NOAA Technical Memorandum NOS CS 26

EVALUATION OF WATER CURRENT AND DENSITY FORECAST GUIDANCE FROM NWS AND U.S. NAVY REAL TIME OCEANOGRAPHIC FORECAST MODELING SYSTEMS

Silver Spring, Maryland
February 2012

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The Office of Coast Survey (OCS) is the Nation's only official chartmaker. As the oldest United States scientific organization, dating from 1807, this office has a long history. Today it promotes safe navigation by managing the National Oceanic and Atmospheric Administration's (NOAA) nautical chart and oceanographic data collection and information programs.

There are four components of OCS:

> **The Coast Survey Development Laboratory develops new and efficient techniques to accomplish Coast Survey missions and to produce new and improved products and services for the maritime community and other coastal users.**
>
> **The Marine Chart Division acquires marine navigational data to construct and maintain nautical charts, Coast Pilots, and related marine products for the United States.**
>
> **The Hydrographic Surveys Division directs programs for ship and shore-based hydrographic survey units and conducts general hydrographic survey operations.**
>
> **The Navigational Services Division is the focal point for Coast Survey customer service activities, concentrating predominately on charting issues, fast-response hydrographic surveys, and Coast Pilot updates.**

NOAA Technical Memorandum NOS CS 26

EVALUATION OF WATER CURRENT AND DENSITY FORECAST GUIDANCE FROM NWS AND U.S. NAVY REAL TIME OCEANOGRAPHIC FORECAST MODELING SYSTEMS

Richard A. Schmalz, Jr. and Philip H. Richardson
Office of Coast Survey, Coast Survey Development Laboratory,
Silver Spring, MD

February 2012

noaa National Oceanic and Atmospheric Administration

U. S. DEPARTMENT OF COMMERCE
John Bryson,
Secretary

National Oceanic and Atmospheric Administration
Dr. Jane Lubchenco,
Under Secretary

National Ocean Service
David Kennedy,
Acting Assistant Administrator

Office of Coast Survey
Captain John Lowell, NOAA

Coast Survey Development Laboratory
Mary Erickson

NOTICE

Mention of a commercial company or product does not constitute an endorsement by NOAA. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

ABSTRACT

NOAA/ National Weather Service (NWS) Real Time Ocean Forecast System (RTOFS) and United States Navy (USN) global Navy Coupled Ocean Model (G-NCOM) salinity and water temperature forecast guidance were compared with the observations from the Global Temperature and Salinity Profile Program (GSTPP) archived at the National Buoy Data Center (NBDC) in water temperature and salinity assess (TESAC) format. No water current observations were available for model comparison so the World Ocean Atlas (2001) climatologically based thermal wind equation derived velocities were used in addition to tidally reconstructed water current signals from the ADCIRC tidal inversion.

Ocean model forecast guidance of salinity, water temperature, and U (Northings) and V (Eastings) water current components along the open boundaries of the National Ocean Service's ROMS-based oceanographic forecast modeling systems for Delaware Bay (DBOFS), Chesapeake Bay (CBOFS), and Tampa Bay (TBOFS) forecast systems were compared with WOA 2001 salinity and temperature climatology, and the thermal wind derived water currents and the reconstructed tidal water currents based on the ADCIRC tidal inversion. A snapshot analysis at the end of the nowcast cycle for the 00 UTC nowcast/forecast cycles was performed for November 2010 and February, May, and August 2011. RTOFS forecast guidance was not available for May and August 2011.

Along the DBOFS open boundary, the G-NCOM surface salinity forecast guidance is nearer the WOA 2001 climatology than the RTOFS surface salinity forecast guidance. This is true as well for the stratification, which for G-NCOM is very close to climatology, while the RTOFS stratification is less pronounced. The mean surface salinity difference is order 2.5 PSU, with RTOFS being saltier than G-NCOM. For surface water temperature forecast guidance RTOFS tends to be warmer by order 1^{o}C and less stratified than the G-NCOM values, which are very close to climatology.

Along the CBOFS open boundary, the G-NCOM surface salinity forecast guidance is nearer the WOA 2001 climatology than the RTOFS surface salinity forecast guidance. This is true as well for the stratification, which for G-NCOM is very close to climatology, while the RTOFS stratification is less pronounced. The mean surface salinity difference is order 2.3 PSU, with RTOFS being saltier than G-NCOM. For surface water temperature forecast guidance RTOFS tends to be warmer by order 0.5^{o}C and less stratified than the G-NCOM values, which are very close to climatology.

Along the TBOFS open boundary, the G-NCOM and RTOFS surface salinity forecast guidance are nearly equal and close to the WOA 2001 climatology. This is true as well for the stratification, with both G-NCOM and RTOFS very close to climatology. For surface water temperature forecast guidance G-NCOM and RTOFS agree to within 0.1^{o}C and are very close to climatology.

While limited TESAC format CTD data versus forecast model comparisons were performed, comparisons were less favorable up the estuaries (mid-Chesapeake Bay station) and at CTD stations near the northern forecast model boundaries.

While this snapshot philosophy is valuable for an initial assessment of salinity and temperature structures, for the more dynamic velocity patterns, the development of a complementary time series based approach is needed and is discussed with respect to more formal evaluation.

1. INTRODUCTION

The National Ocean Service's coastal ocean and estuarine nowcast/forecast modeling systems require specification of the offshore boundary conditions for water level, water density, and water currents. These boundary conditions must be provided from basin scale or global numerical forecast models, since observation density is insufficient in time and space to meet the necessary requirements. Previous studies have focused on the evaluation of water level forecast guidance (Richardson and Schmalz, 2007; Richardson and Schmalz, 2009; Schmalz and Richardson, 2011). This study focused on the evaluation of water density and water current forecast guidance. First, to facilitate the discussion, we briefly review the characteristics of the ocean forecast models considered. Next, the Conductivity, Temperature, Depth (CTD) sensor datasets used in the evaluation are described.

Ocean Model Description

The National Weather Service's Real Time Ocean Forecast System (RTOFS) for the Atlantic Ocean Basin runs at the National Centers for Environmental Prediction (NCEP) and uses the Hybrid Coordinate Ocean Model (HYCOM) as described by Mehra and Rivin (2010). The HYCOM is configured with 1200 x 1684 points in the horizontal as shown in Figure 1.1 and 18 isopyncnal and 7 z-levels in the vertical. Surface forcings, in the form of 10-m winds and sea-level atmospheric pressure and surface fluxes are from the 3-hour NCEP Global Forecast System (GFS), a numerical weather prediction modeling system. The open boundaries are relaxed to NCEP climatology. Tides are included in terms of tidal potential and boundary tides specified in terms of the M_2, S_2, N_2, K_2, K_1, P_1, O_1, and Q_1 tidal constituents. River inputs are specified from US Geological Survey (USGS) daily streamflow data and climatology. In the previously analyzed operational version (Richardson and Schmalz, 2007; Richardson and Schmalz, 2009; Schmalz and Richardson, 2011), SST data from the GOES AVHRR are assimilated in RTOFS. In the November 2009 operational version, improvements to the tidal dynamics have been made and SSH data assimilation has been incorporated. Refer to Bleck et al. (2002) for further details regarding the HYCOM model development and computational algorithms. River inflow data for U.S. rivers are from the USGS and from the RivDIS climatology (http://www.rivdis.sr.unh.edu/) for foreign rivers. Surface forcing is provided by the GFS 3 hourly model output. Each cycle produces a 24 hour nowcast, and a 120 hour forecast.

The U.S. Navy (USN) Global Coastal Ocean Model (G-NCOM) system is run on a 1/8 by 1/8 degree grid as shown in Figure 1.2 as described by Barron et al. (2004; 2006) . G-NCOM uses the Princeton Ocean Model (POM) configured with 41 levels with 19 sigma-coordinate layers in the upper 137m and 21 z-level coordinate layers from 137m to 5500m. See Blumberg and Mellor (1987) and Blumberg and Herring (1987) for computational details and Martin (2000) for operational implementation. The daily 00 UTC forecast cycle has a horizon out 72 hours and is forced by U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) winds and Multi-Channel Sea Surface Temperature (MCSST). Barotropic tides are added from the Oregon State global ¼ by ¼ degree TPXO6.2 tidal model (Egbert and Erofeeva, 2002) for the same eight constituents used in RTOFS as well as two long period constituents (M_f, M_m). Note G-NCOM forecast data are being distributed via the Northern Gulf Institute in the above numbered Regions 1, 2, 5,6,7, and 10. Ocean NOMADS provides archives of the three areas that cover North America and Hawaii: Regions 1, 6, and 7. Region 1 contains the western North Atlantic and Gulf of Mexico and is considered in this report.

CTD Evaluation Datasets

The Global Temperature-Salinity Profile Program (GTSPP) is a cooperative international project that seeks to develop and maintain a global ocean Temperature-Salinity resource with up-to-date high quality data. The goal is to make water temperature and salinity measurements quickly and easily accessible. Both real time data transmitted over the Global Telecommunications System (GTS), and delayed-mode data received by the NODC and NBDC are acquired and incorporated into a continuously managed database (UNESCO-IOC, 2010). The locations of several major stations, which report to NBDC, are given in the Gulf of Mexico in Figures 1.3 - 1.10 and along the Atlantic coast in Figures 1.10 – 1.17, respectively. Several of these stations are used in the monthly snapshot CTD evaluations given in subsequent tables.

Report Organization

In Chapter 2, we describe the development and application of an initial evaluation Fortran 90 based program to assess the ability program of the above ocean nowcast/forecast models to provide water current, salinity, and water temperature boundary conditions. A separate NCAR based plot program was developed to provide graphics and summary statistic files to further aid the evaluation process. The development of a snapshot type approach and its initial test application for October 2010 is presented. Chapter 3 presents a monthly evaluation of the water current and density forecast guidance for a snapshot in mid-November 2010. Results are presented in terms of CTD profile comparisons versus observed CTD profile data and in terms of comparisons with climatologically derived water currents and salinity and temperature along the open boundaries of the ROMS-based nowcast/forecast systems for Delaware Bay, Chesapeake Bay, and Tampa Bay. In Chapters 4-6, we present snapshot analyses in mid-February, mid-May, and in mid-August 2011 in the same format. Chapter 7 presents some conclusions drawn from the work as well as recommendations for additional ocean model water current and density evaluation utilizing a complementary time series based approach. A description of the complete analysis procedures is presented in the Appendices A-D, while processing and analysis notes for February 2011 are given in Appendices E and F, respectively.

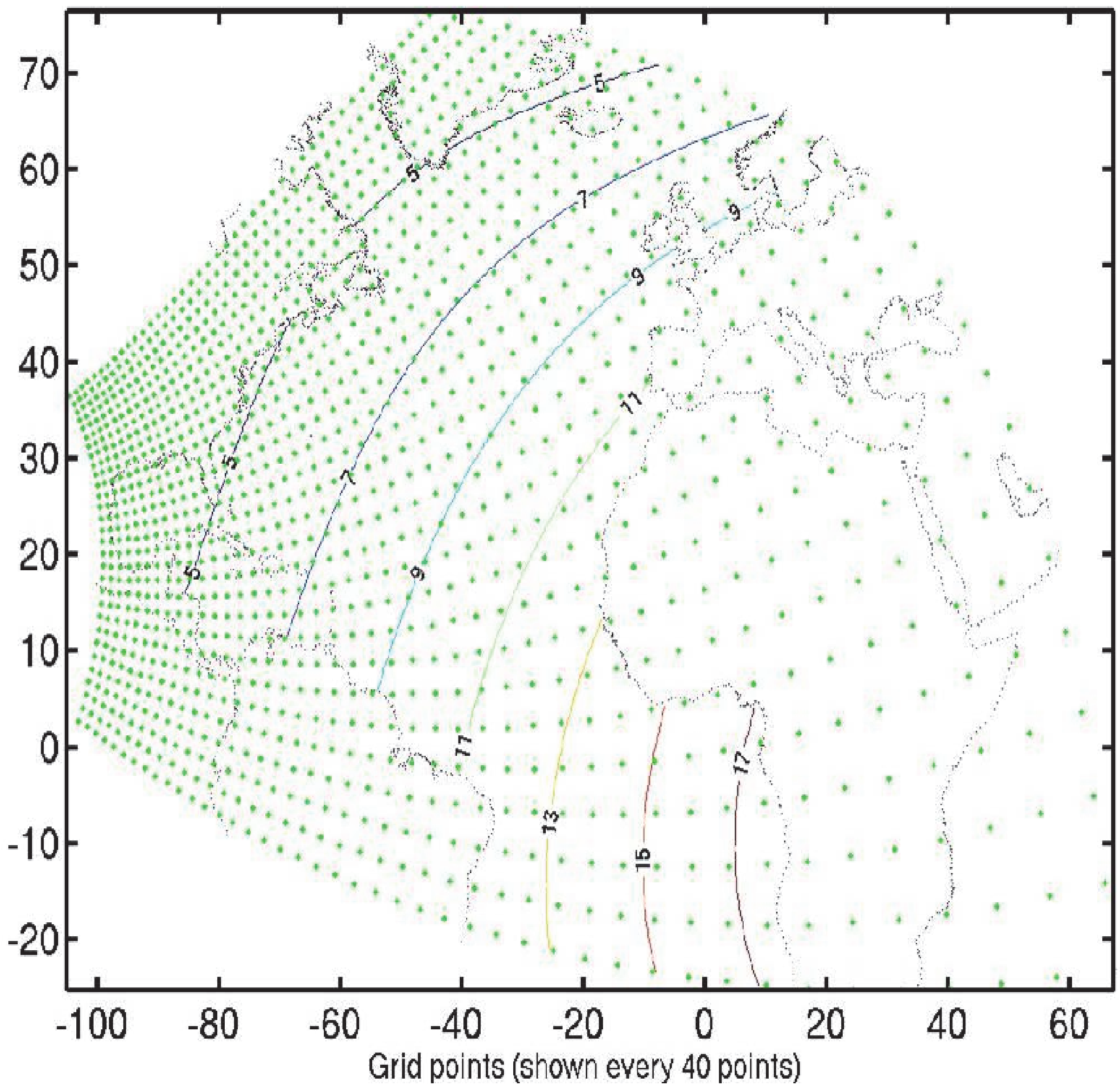


Figure 1.1. RTOFS Grid with spacing from 5 to 17 km. Note only every fortieth grid point shown.

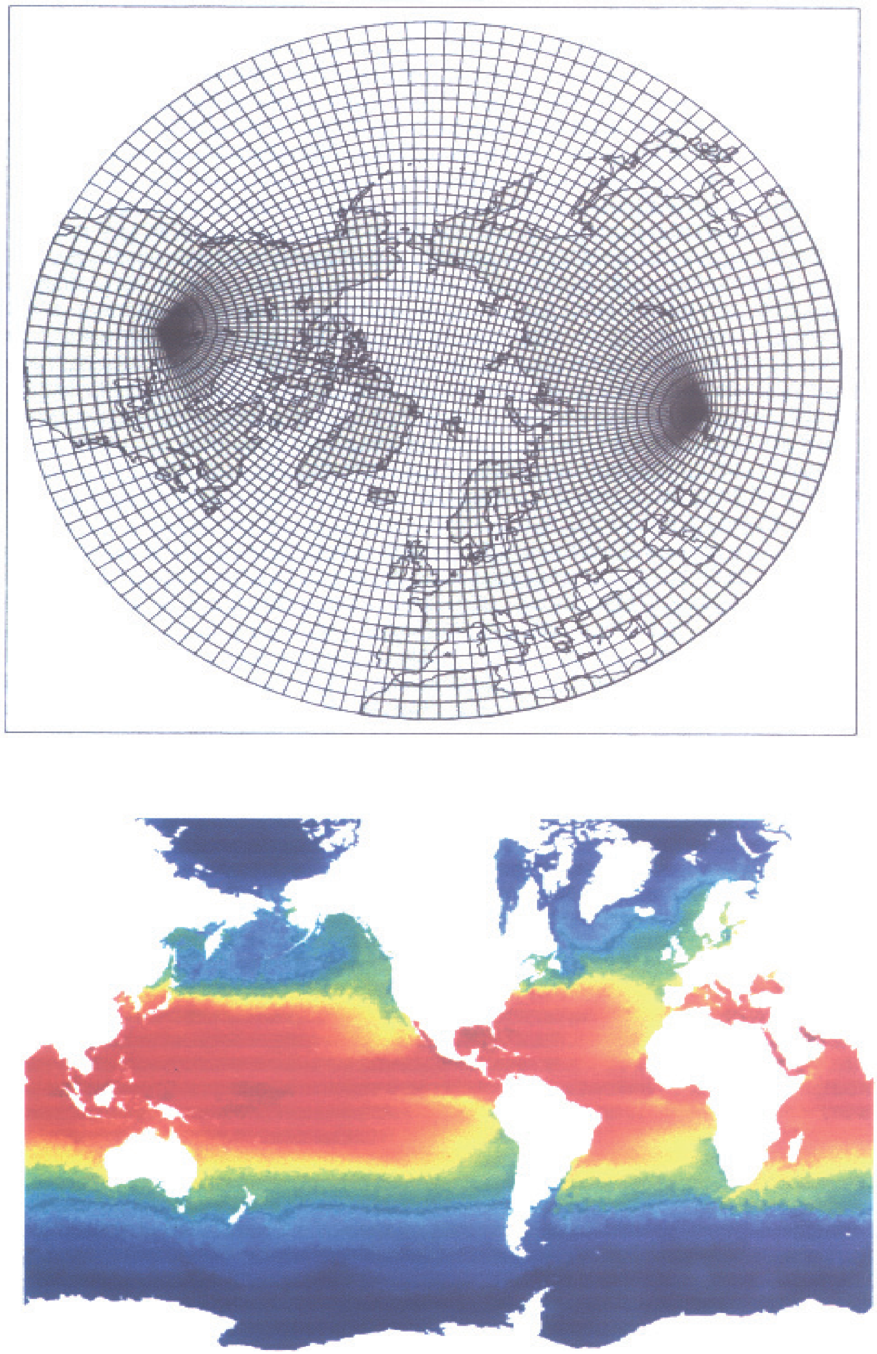


Figure 1.2. Global Navy Coastal Ocean Model (G-NCOM) horizontal grid. In the upper panel, the Arctic cap to 30 ^{o}N is shown, with only every sixteenth line of grid points plotted. In the lower panel, the surface water temperature on the horizontal grid from 80^{o}S to the Arctic Cap (from Rowley et al., 2002).

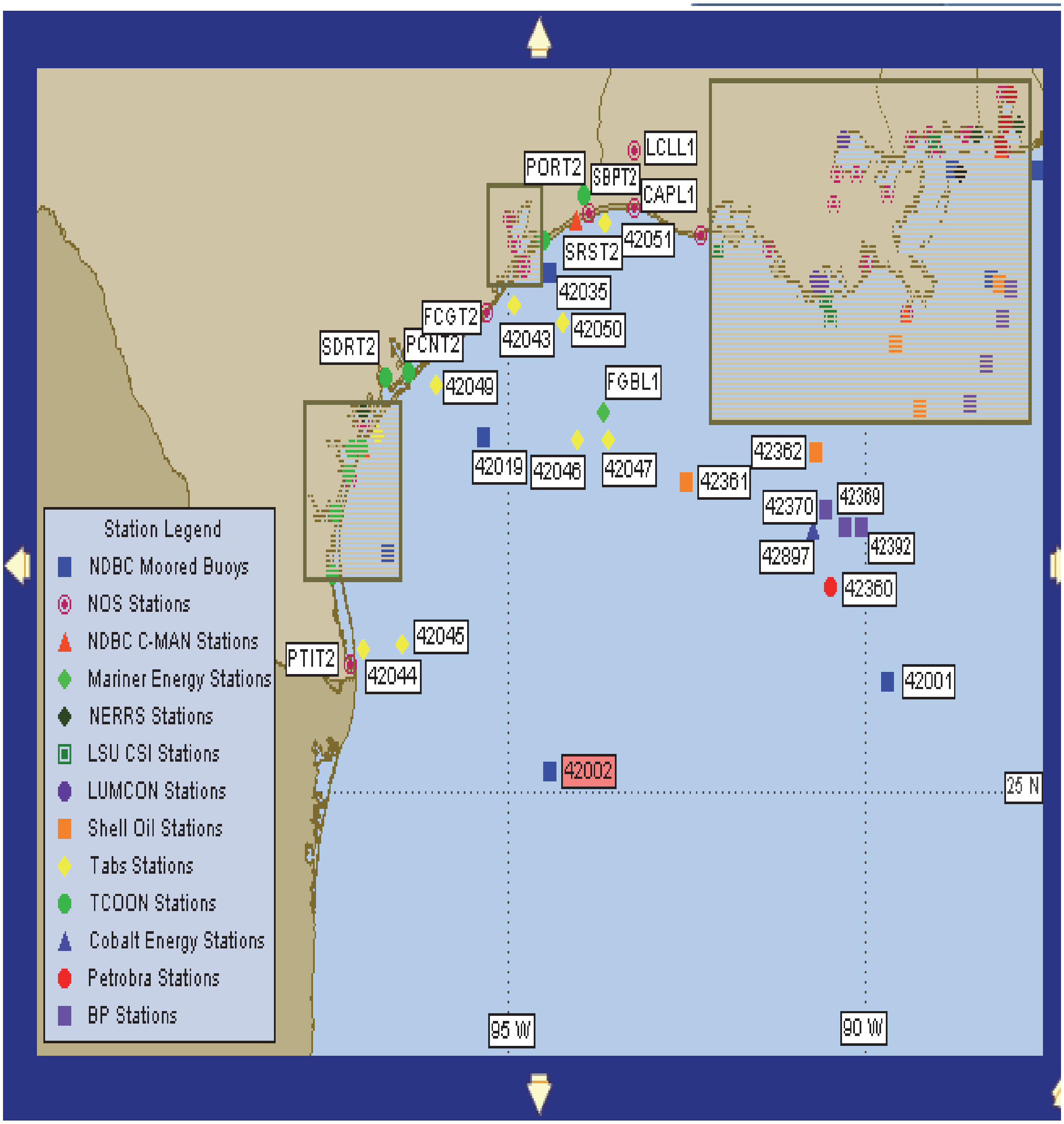


Figure 1.3. NBDC CTD stations in Western Gulf of Mexico. Inserts are shown as separate figures.

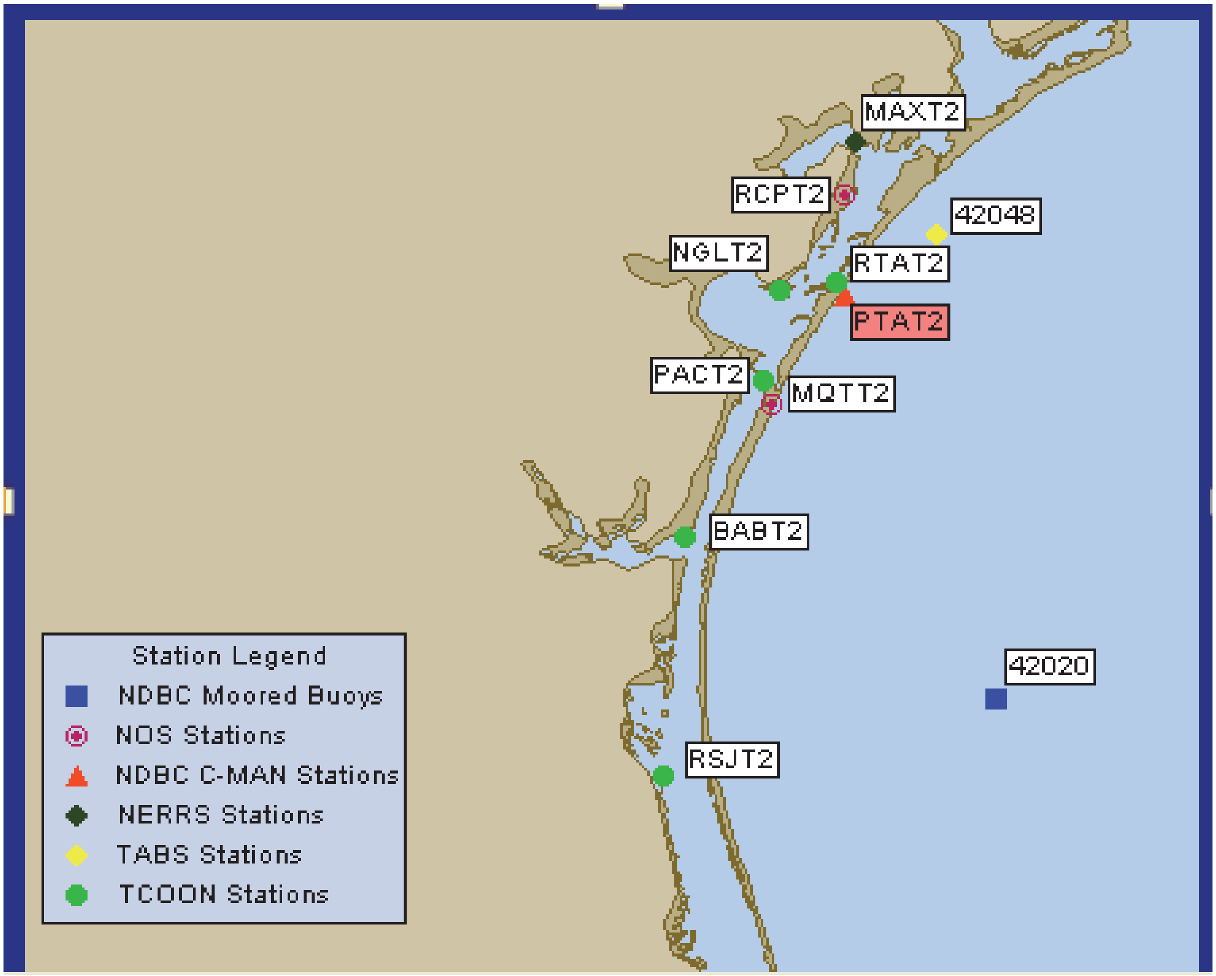


Figure 1.4. NBDC CTD stations along the South Texas Coast. Insert 1 to Figure 1.3.

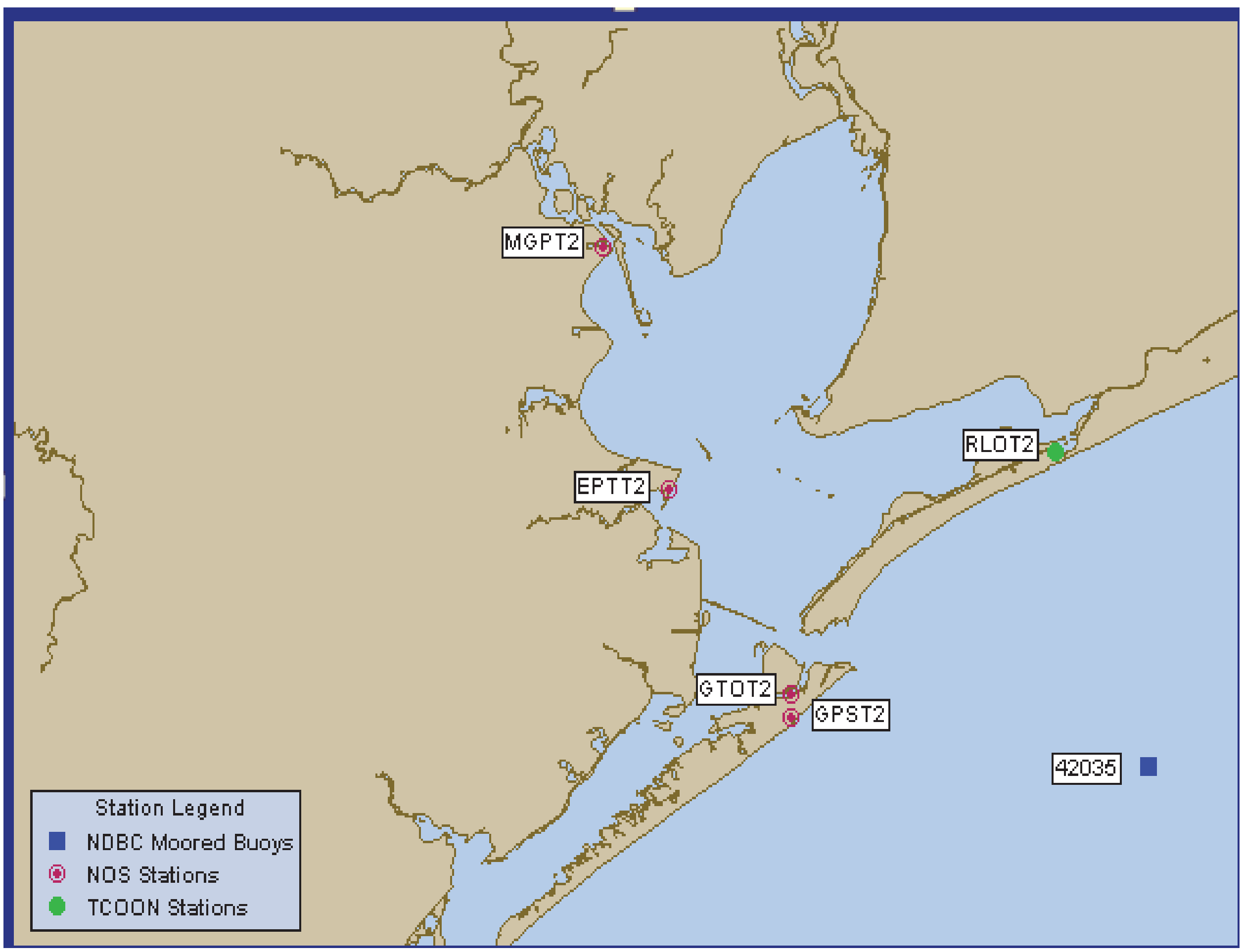


Figure 1.5. NBDC CTD stations in Galveston Bay and offshore along the North Texas Coast. Insert 2 to Figure 1.3.

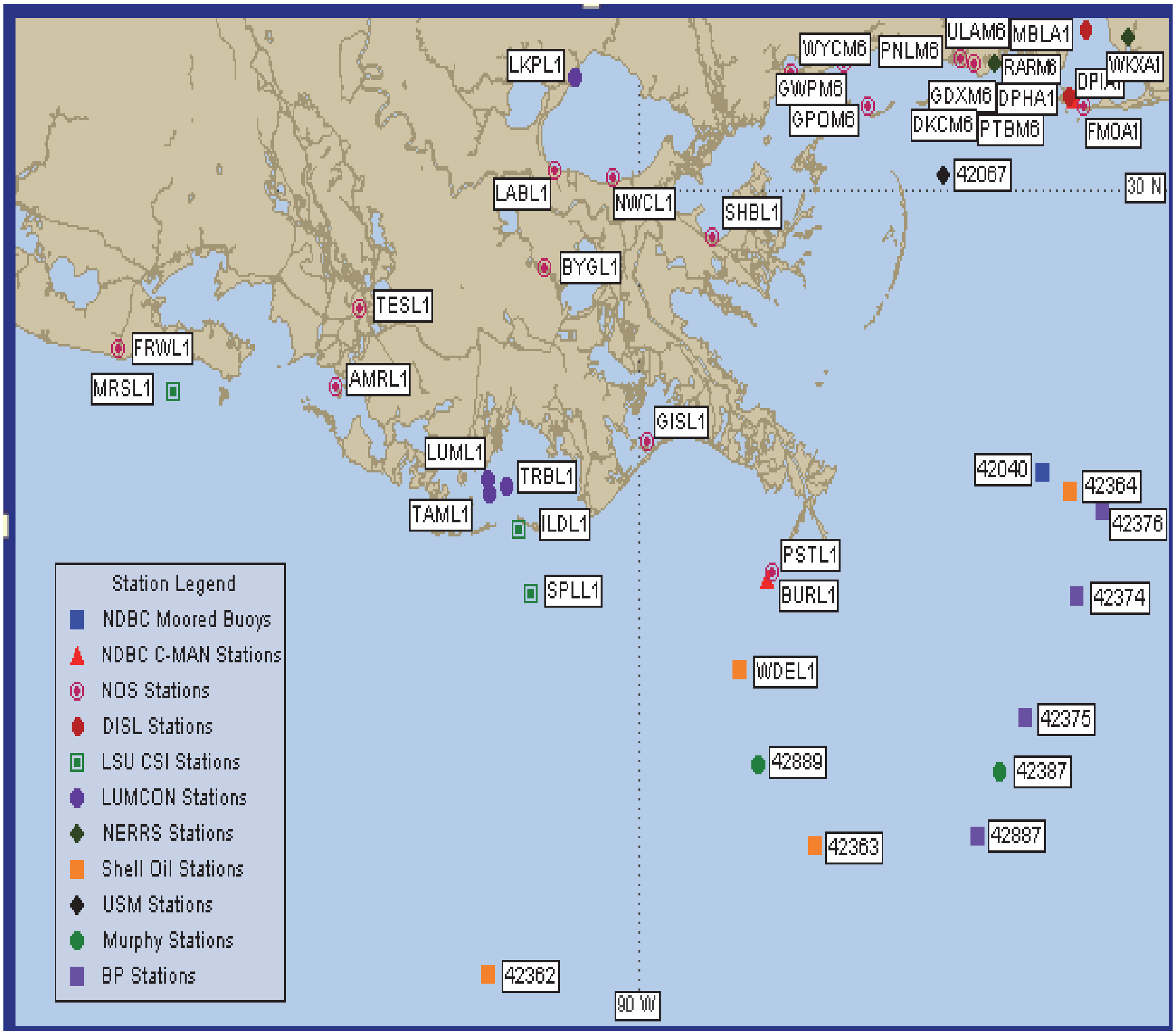


Figure 1.6. NBDC CTD stations offshore along the Louisiana, Mississippi, and Alabama North Gulf Coast. Insert 3 to Figure 1.3.

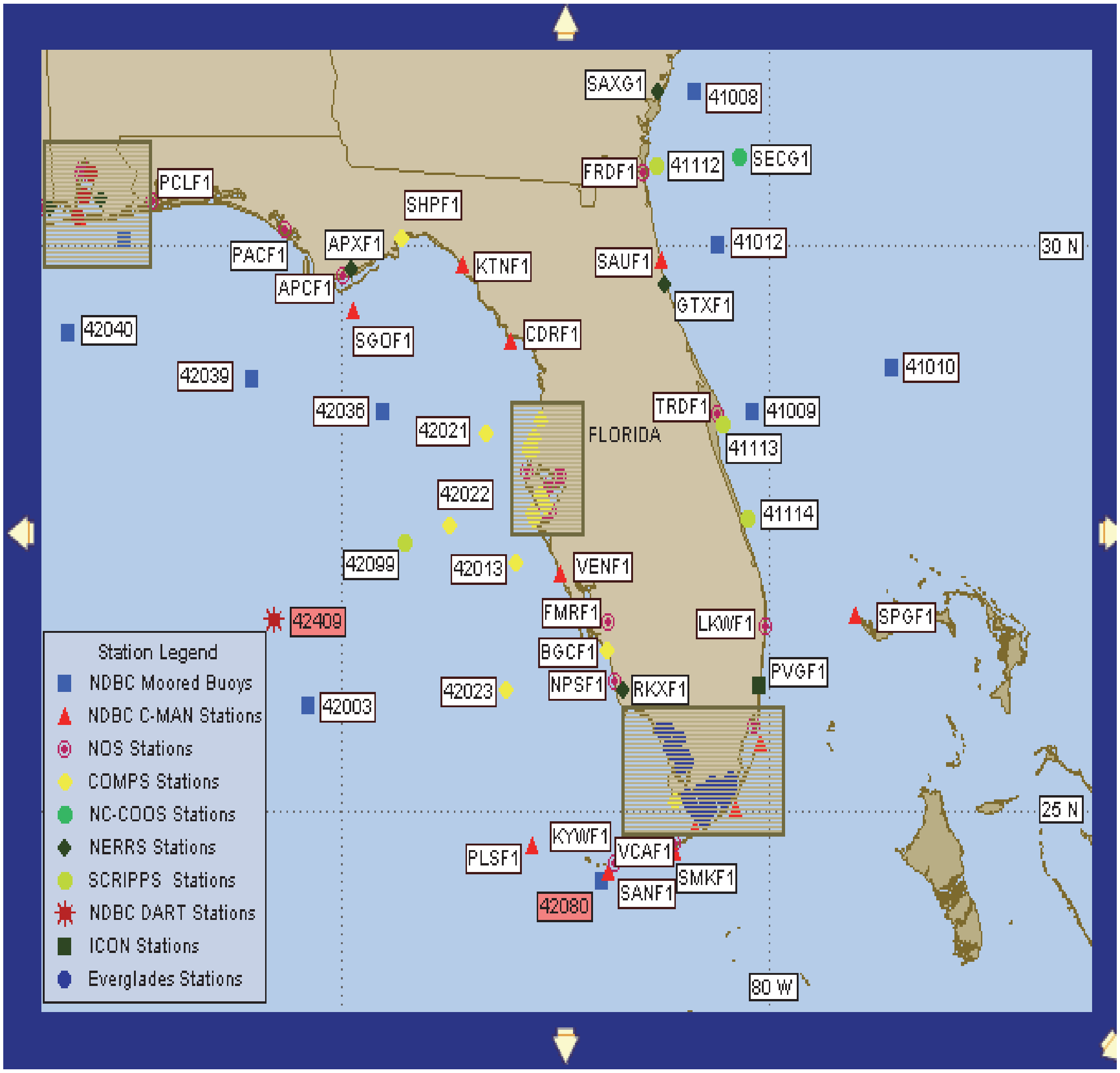


Figure 1.7. NBDC CTD stations offshore along the Eastern Alabama and Florida Gulf Coasts and Florida and South Georgia Atlantic Coasts. Inserts are shown in separate figures.

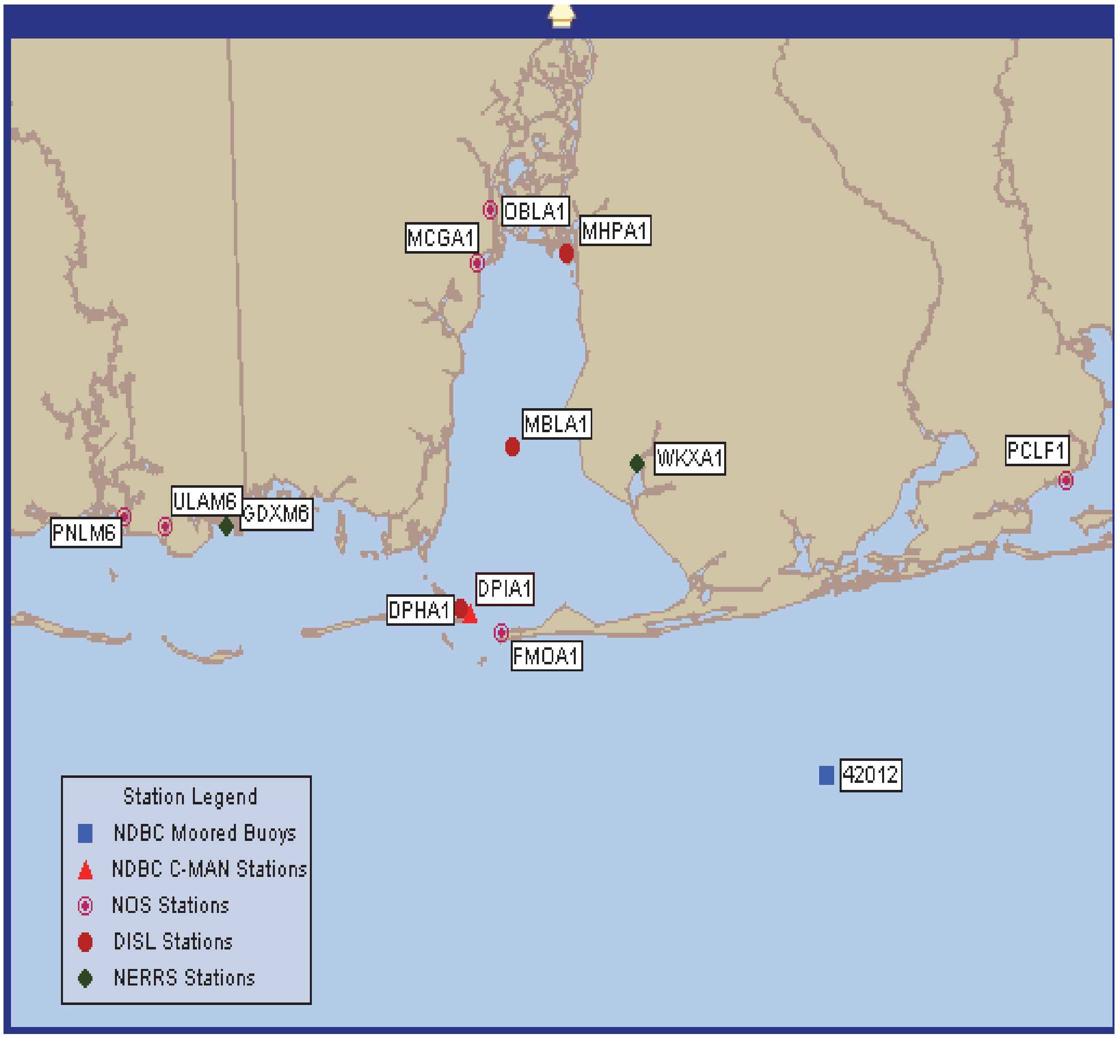


Figure 1.8. NBDC CTD stations in Mobile Bay and offshore. Insert 1 to Figure 1.7.

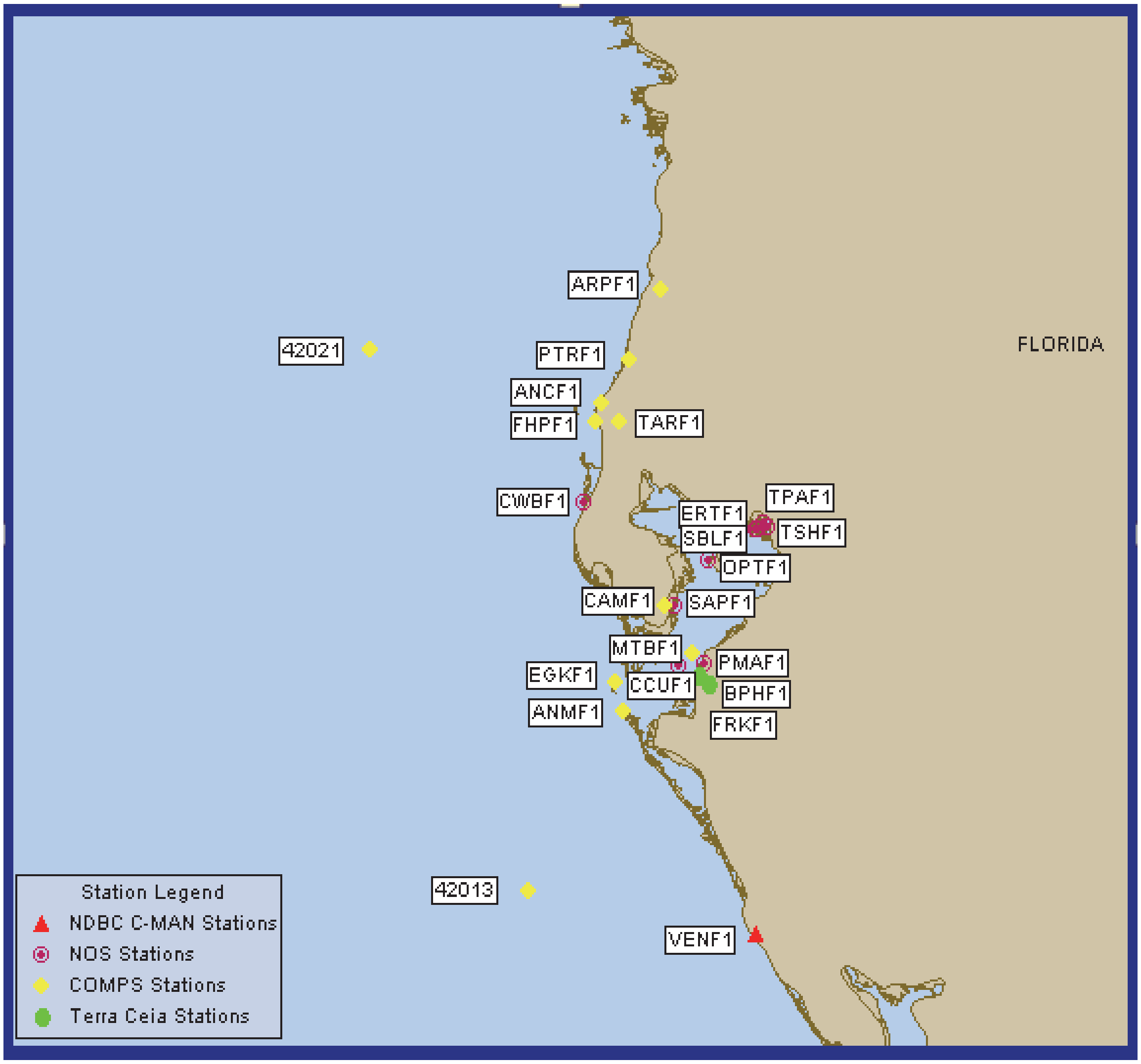


Figure 1.9. NBDC CTD stations in Tampa Bay and offshore. Insert 2 to Figure 1.7.

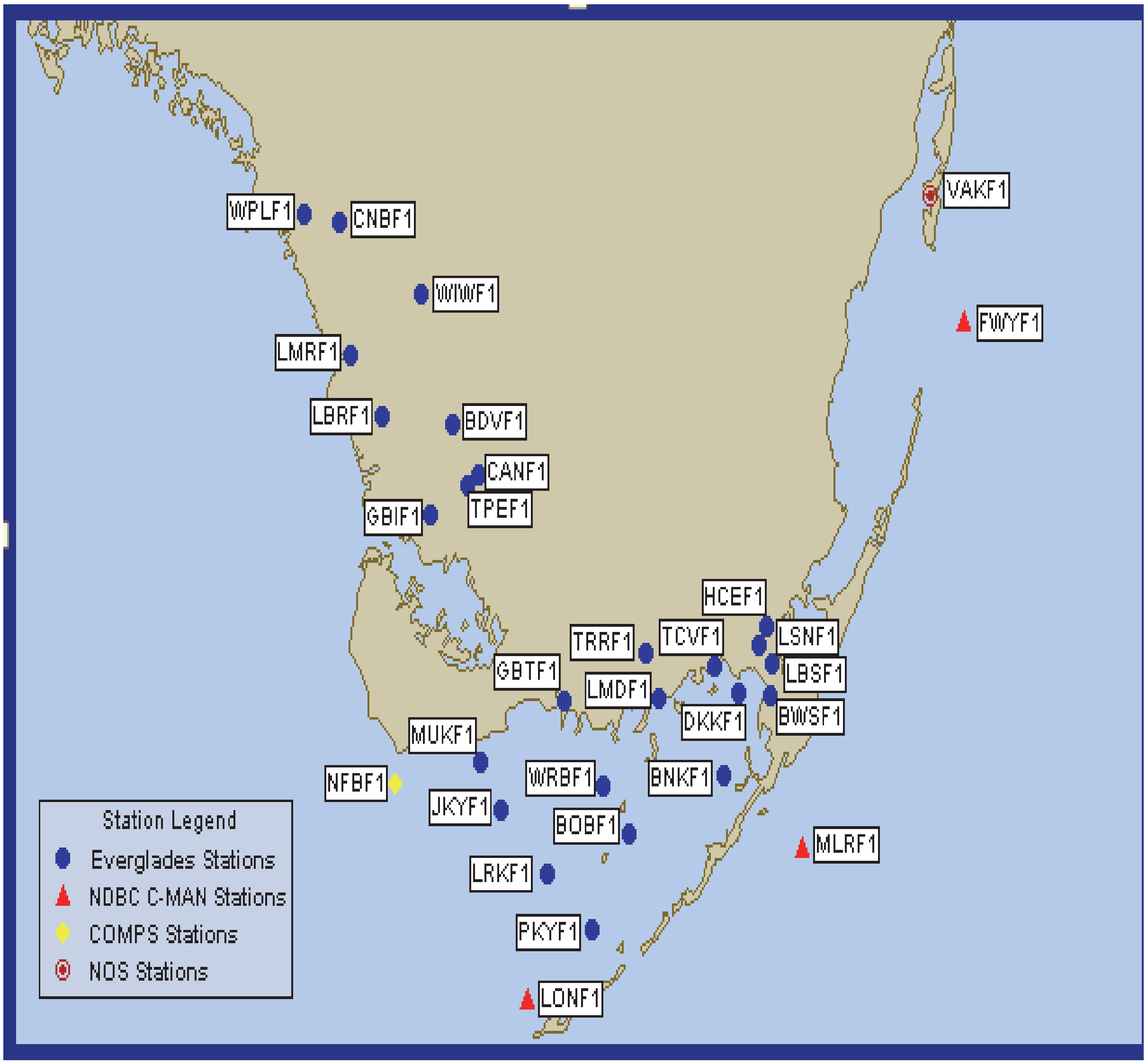


Figure 1.10. NBDC CTD stations in Florida Bay and offshore. Insert 3 to Figure 1.7.

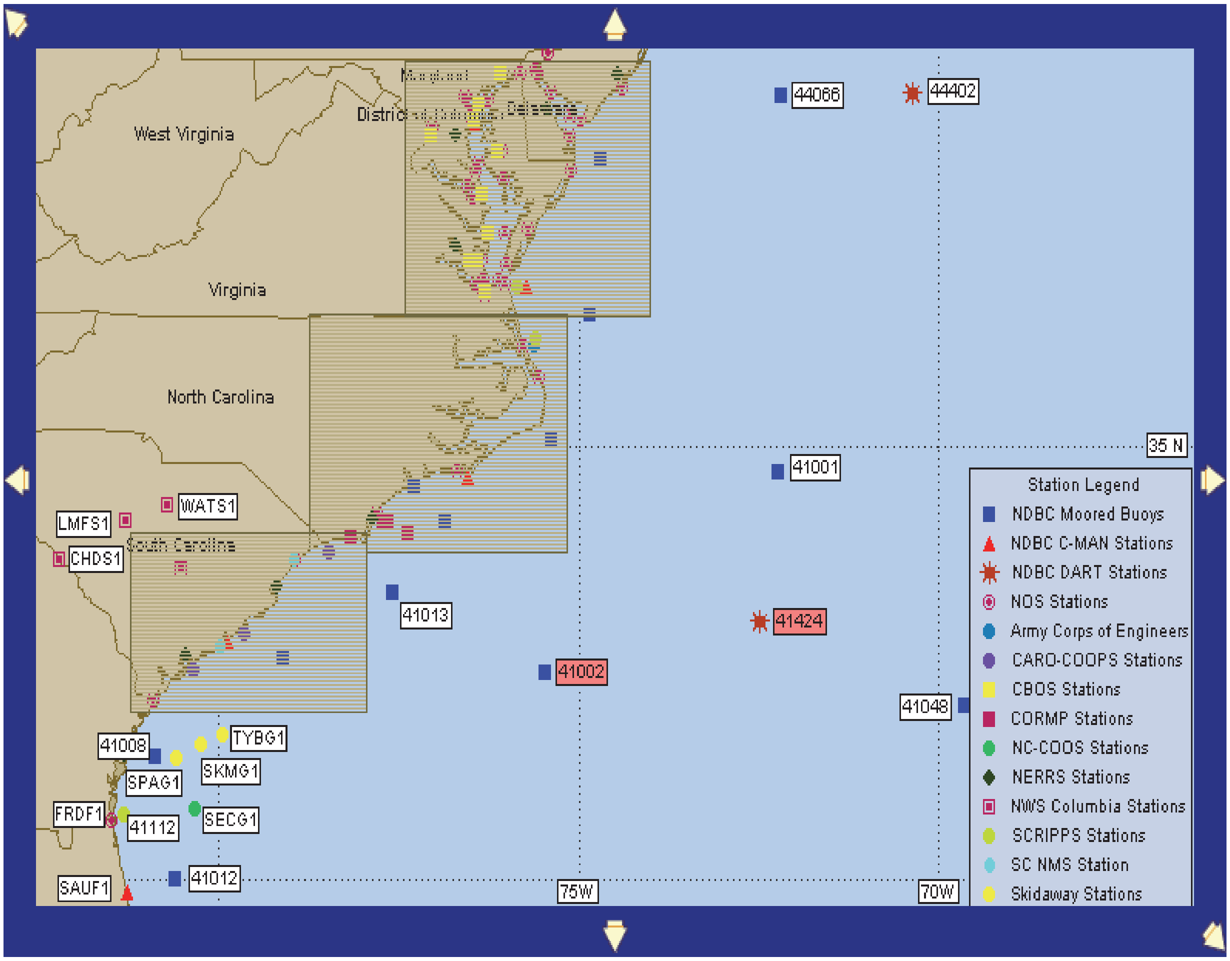


Figure 1.11. NBDC CTD stations along the mid-Atlantic Coast. Inserts shown in separate figures.

Figure 1.12. NBDC CTD stations along the South Carolina Coast. Insert 1 to Figure 1.11.

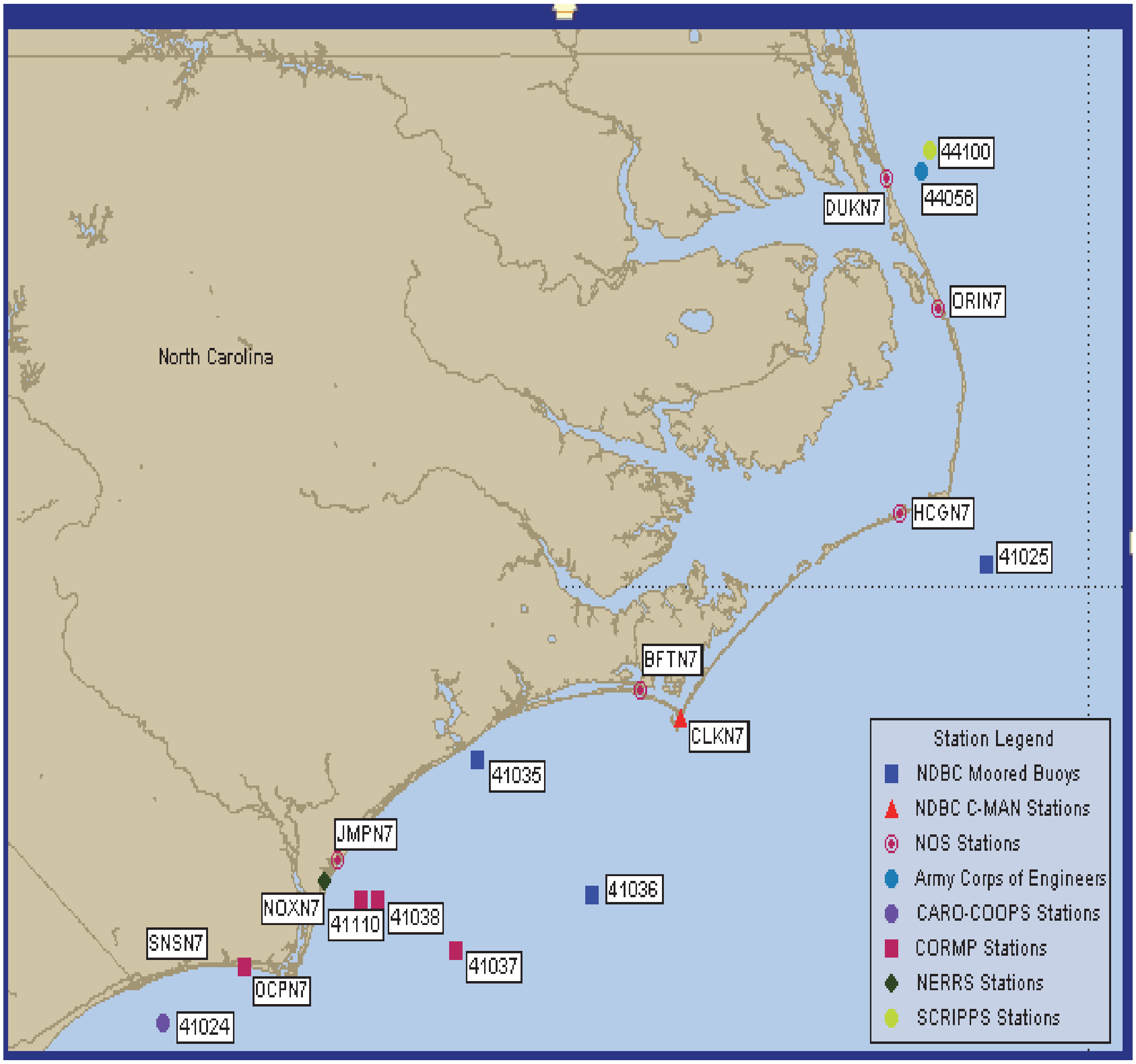


Figure 1.13. NBDC CTD stations along the North Carolina Coast. Insert 2 to Figure 1.11.

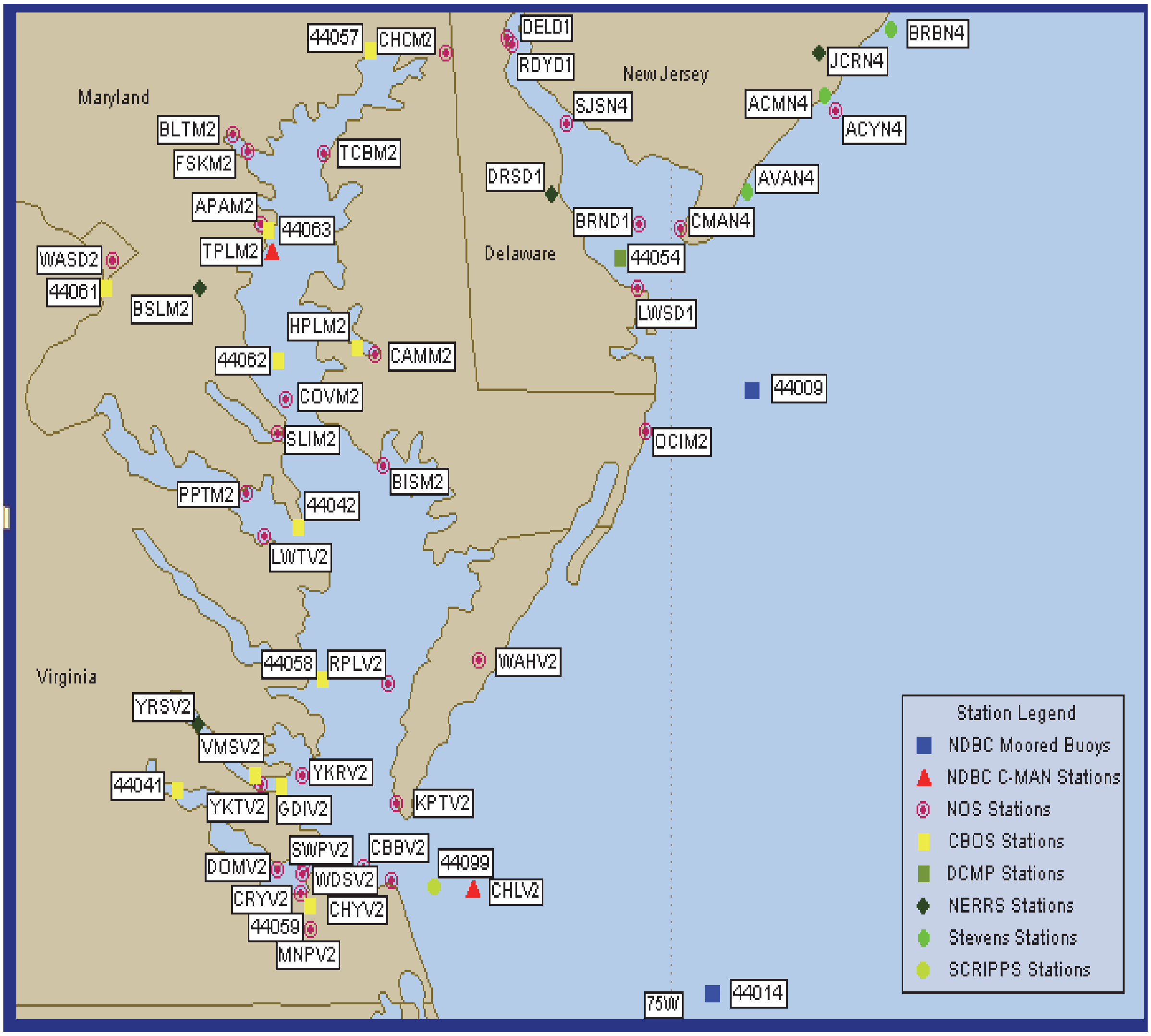


Figure 1.14. NBDC CTD stations in Chesapeake and Delaware Bays and offshore. Insert 3 to Figure 1.11 and Insert 1 to Figure 1.15.

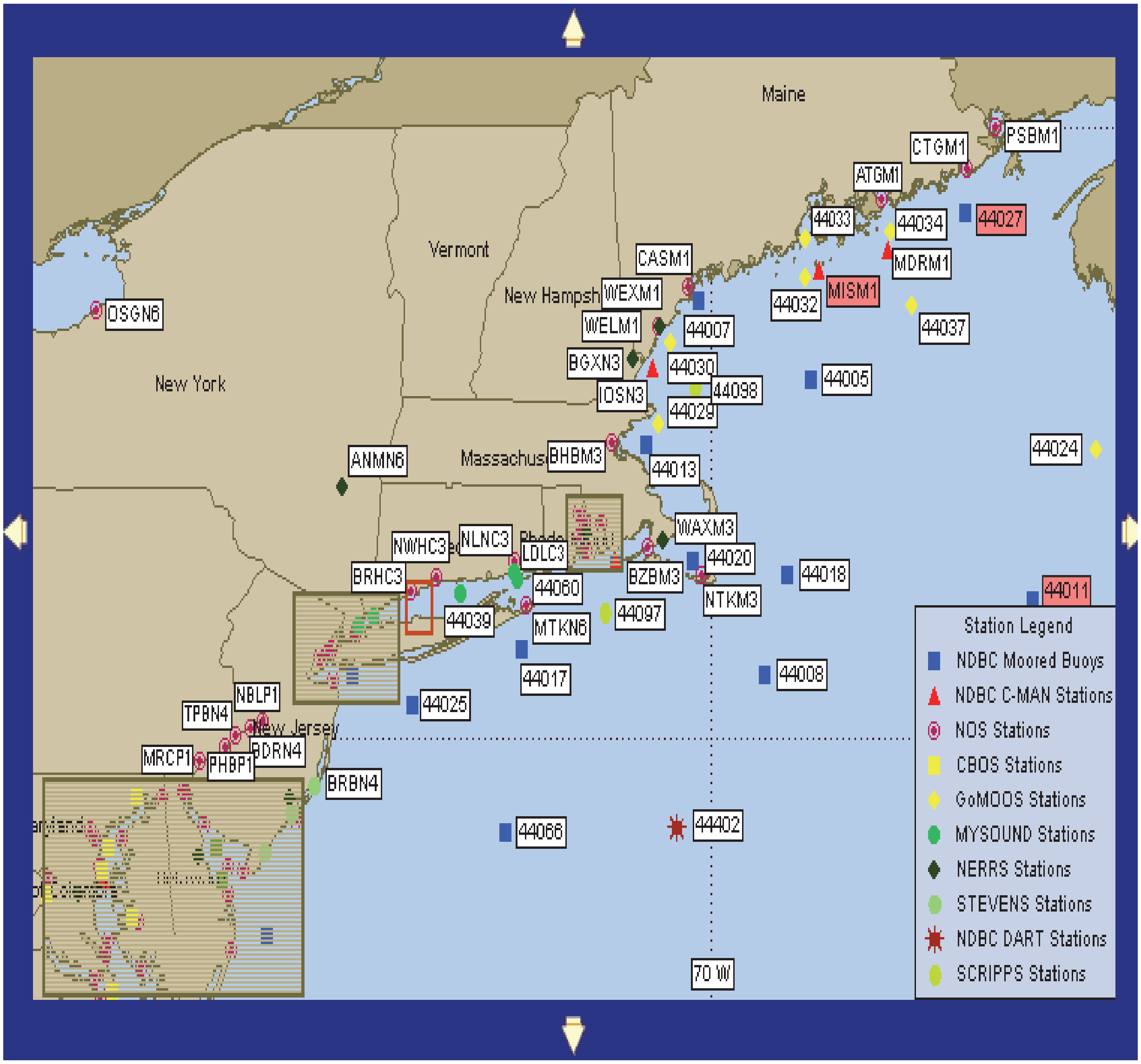


Figure 1.15. NBDC CTD stations along the Northern Atlantic Coast. Inserts shown in separate figures. Note Insert 1 is shown in Figure 1.15 as Insert 3 to Figure 1.11.

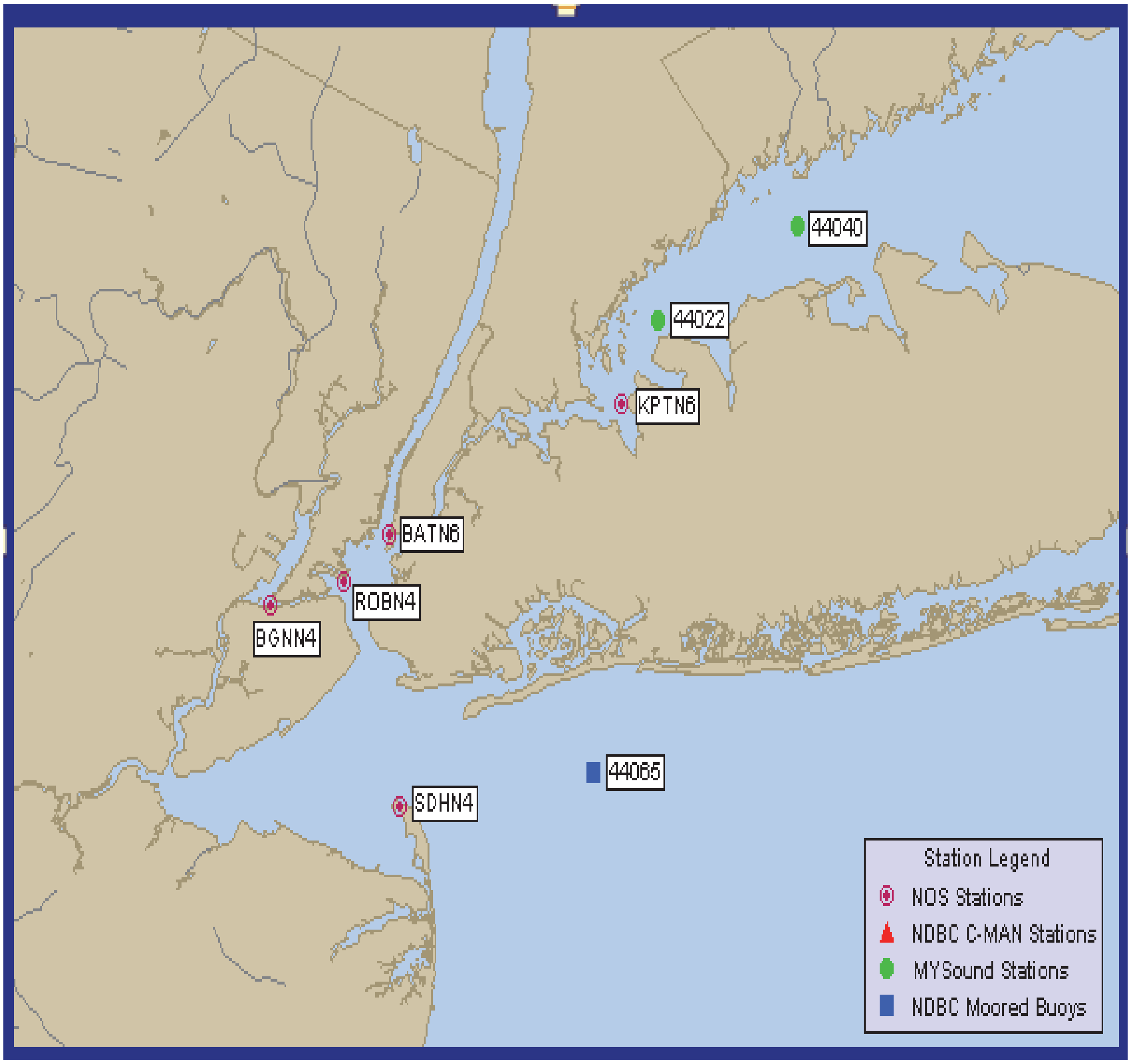


Figure 1.16. NBDC CTD stations in New York Harbor and Western Long Island Sound. Insert 2 to Figure 1.15.

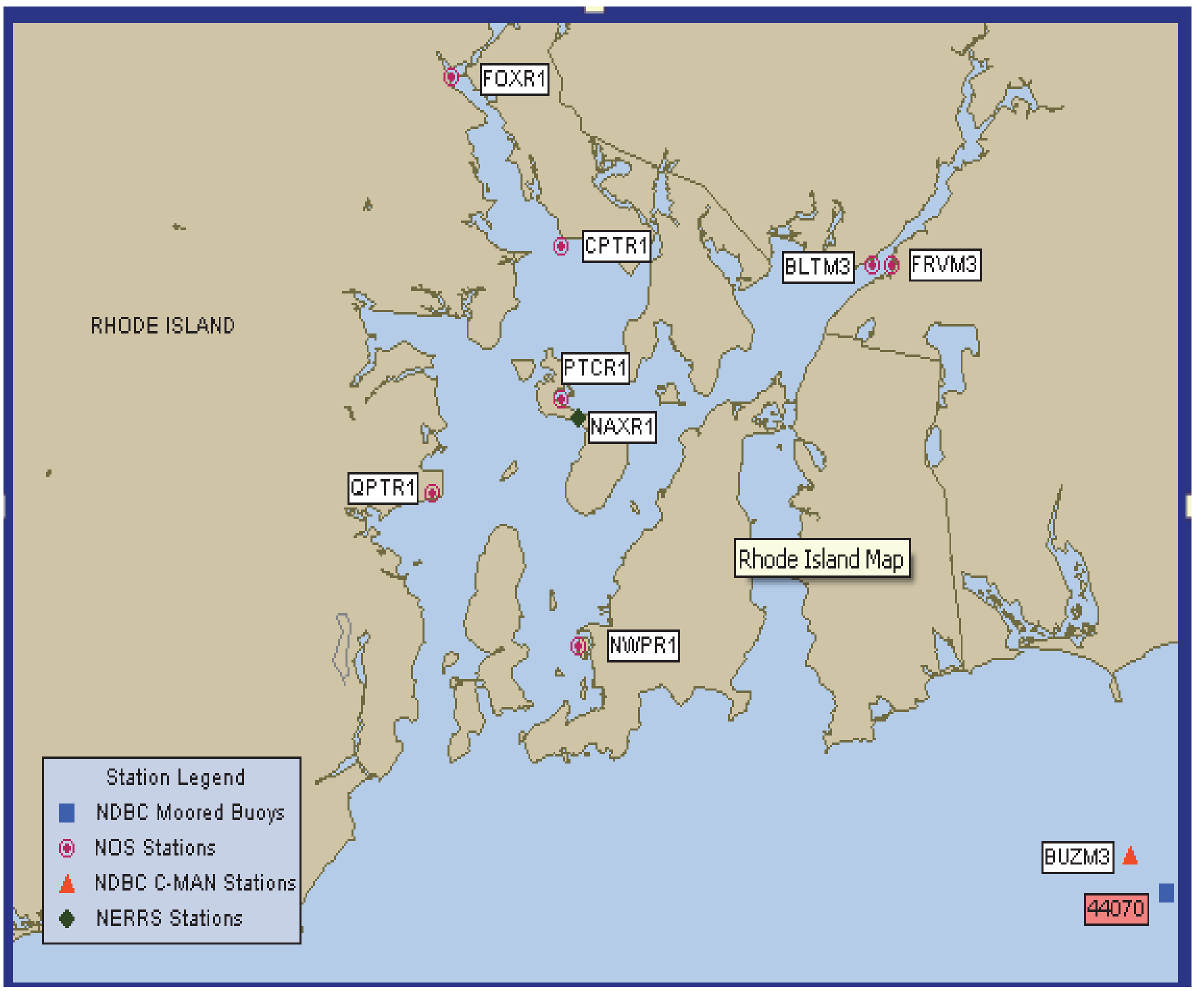


Figure 1.17. NBDC CTD stations in Narragansett Bay and Eastern Long Island Sound. Insert 3 to Figure 1.15.

2. WATER CURRENT AND DENSITY EVALUATION PROCEDURES

Separate analysis and plot programs were written to evaluate the salinity, water temperature, and water current predictions for RTOFS and G-NCOM along the open boundaries of the three next generation ROMS based OFSs in Delaware Bay (Figure 2.1), Chesapeake Bay (Figure 2.2), and Tampa Bay (Figure 2.3). The analysis program (ocean_model_evalp.n.f) is written in Fortran 90 and employs dynamically allocated arrays as well as modules in place of common blocks. It is based on a snapshot philosophy in which the ocean model fields are accessed at the start of the 00 UTC forecast; e.g., at the end of the nowcast, on two consecutive days. The program employs a nested three loop structure, with the outermost loop corresponding to the ocean model, the next inner loop corresponding to the OFS, and the innermost loop corresponding to the snapshot. For validation, the TESAC CTD profile data are accessed from the RTOFS forecast directories, while for further forecast evaluation, the World Ocean Atlas 2001 climatological datasets and the ADCIRC tidal inversion datasets are read.

To obtain the model predictions over the three OFS regions, the NOAA/NOMADS OPeNDAP server (http://edac-dap2.northerngulfinstitute.org/ocean_nomads) was accessed. For RTOFS separate files for the salinity and water temperature and horizontal velocity components were obtained due to file size. For G-NCOM all fields were obtained in a single ascii file. Since the files use brackets and comma separators, as well as other special characters, it is necessary to edit the files prior to use by the analysis program. For further details, the reader is referred to the appendices.

The analysis program was structured to first specify a depth range (0 to 250 m) and horizontal domain (27 to 40 ^{o}N, -85 to -73 ^{o}W) to define the ocean domain. Next the user specifies the number of snapshots to consider. Initially three snapshots (5/15, 5/31, and 6/13/2010) at 00 UTC were used to test the analysis procedure. Each ocean model is considered separately. For each ocean model, an interpolation of WOA 2001 climatology for salinity and water temperature over the ocean domain is performed (Conkright et al., 2002). In addition, a geostrophic reference velocity is computed for each of the three OFSs at an adjacent deep water location (DBOFS 37.5 ^{o}N, -73.0 ^{o}W; CBOFS 37.0 ^{o}N, -74.0 ^{o}W; TBOFS 27.5 ^{o}N, -84.0 ^{o}W) using the thermal wind equations with an assumed level of no motion of 2000 m. Next the ADCIRC tidal inversion water current harmonic constituents are accessed and the vertically integrated U (East) and V (North) tidal velocity components determined at hour 00 UTC at each snapshot. See Luettich et al. (1992) and Kolar et al. (1994) for ADCIRC computational details and Mukai et al. (2001) and Myers (2007) for information on the tidal inversion methodology. The ocean model forecast salinity, water temperature, and horizontal water velocity components are placed along the open boundary of the corresponding OFS model depths and written to a transfer file.

In addition, the National Buoy Data Center (NBDC) buoy archived TESAC CTD data for each snapshot are interpolated to the ocean model depths at the corresponding ocean model grid location and written to a second transfer file. The NCAR based plot program (oceanmodel_plot.f) accesses both transfer files.

For transfer file one, water temperature and salinity profiles are plotted for each NBDC buoy profile. For the initial testing, the NBDC buoy data profile for 6/14/2010 was used for all three snapshots, with the results only slowly degrading from 6/13 to 5/31 to 5/15/2010 indicating a monthly decorrelation time scale for salinity and water temperature.

For the second transfer file, the RMS difference and Willmott et al. (1985) relative difference between the ocean model predictions for salinity and water temperature and the WOA 2001 climatology at three depths (surface, mid-depth, and bottom) along each of the OFS open boundaries at every 10th grid point are computed and plotted. For the U and V water velocity components, the RMS difference and Willmott et al. (1985) relative difference with respect to the ADCIRC tidal inversion based vertically integrated tidal velocity components and with respect to the WOA 2001 based geostrophic reference velocity components are computed along each of the OFS open boundaries at every 10th grid point and plotted.

Here, we consider the results for 10/20/2010, which is used to represent October 2010 conditions. In Tables 2.1 and 2.2, water temperature and salinity ocean model predictions are compared with NBDC buoy data at several locations shown in Chapter 1.

Table 2.1. Water Temperature (^{o}C) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC-ATL=South Carolina Atlantic, FL-ATL=Florida Atlantic, FL-GM=Florida Gulf of Mexico.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033 SC-ATL	0	12 20	0.88 1.09	23.68 23.91	23.31 25.46	23.93 24.02	24.00 22.87	0.43 2.48	0.02 0.10
41012 FL-ATL	0	35 50	1.26 1.43	26.06 26.65	26.48 26.47	24.17 22.64	26.14 25.87	-1.55 -3.41	-0.06 -0.13
42013 FL-GM	0	35 30	1.96 1.70	26.52 26.14	25.76 25.76	25.01 26.18	28.00 28.00	0.72 2.19	0.03 0.08

Table 2.2. Salinity (PSU) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC-ATL=South Carolina Atlantic, FL-ATL=Florida Atlantic, FL-GM=Florida Gulf of Mexico.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033	0	12	0.34	35.44	35.01	35.62	36.00	0.81	0.02
SC-ATL		20	0.30	36.18	35.79	36.18	35.89	0.10	0.00
41012	0	35	0.22	36.06	35.42	36.19	36.17	0.63	0.02
FL-ATL		50	0.23	36.26	36.03	36.38	36.03	-0.12	0.00
42013	0	35	0.40	35.49	35.10	36.10	36.13	0.42	0.01
FL-GM		30	0.65	35.32	35.10	35.35	36.13	1.01	0.03

To aid in the comparisons the following stratification indices are used:

Stratification index 1, $S.I.1 = \left| Y_m - Y_o \right|$

Stratification index 2, $S.I.2 = S.I.1 / 0.5(X_b^o + X_s^o)$

where $Y_m = \left| X_b^m - X_s^m \right|$ and $Y_o = \left| X_b^o - X_s^o \right|$, where $X_b^o, X_s^o\ X_b^m$, and, X_s^m are surface and bottom, observed and model predicted values of salinity or water temperature, respectively. Note in Table 2.1 and Table 2.2 the ocean model depths are different due to grid cell size difference and difference in bathymetric source information.

In Tables 2.3 and 2.4, ocean model salinity and water temperature comparisons against the WOA 2001 climatology are given along the open boundaries of the three new OFSs. Note that the ocean model depths are slightly different corresponding to the difference in average bottom levels along the OFS ocean model boundaries as represented by the given ocean model. Note that the WOA 2001 climatology is not an instantaneous observation, but is based on a large number of observations over the given month.

Similarly, in Tables 2.5 and 2.6, the U (East) and V (North) water velocity component comparisons against the ADCIRC tidal inversion based vertically integrated tidal water current prediction and the World Ocean Atlas 2001 based geostrophic reference velocity are given. Both are not observations. Note both ocean forecast models, G-NCOM and RTOFS, contain the influence of the tides. The geostrophic velocity is based on an assumed level of no motion and climatological density from salinity and water temperature profiles and does not contain any tidal influence. It varies with depth but is at a fixed deep water location off the given OFS boundary. On the other hand, the ADCIRC model predictions do not contain any density influences and are strictly estimates of tidal water surface elevation and vertically integrated tidal water currents, since ADCIRC is a two-dimensional vertically integrated model. No influence of meteorological forcings (wind and atmospheric pressure gradients) are included in the Levitus geostrophic velocity estimate and the ADCIRC tidal velocity.

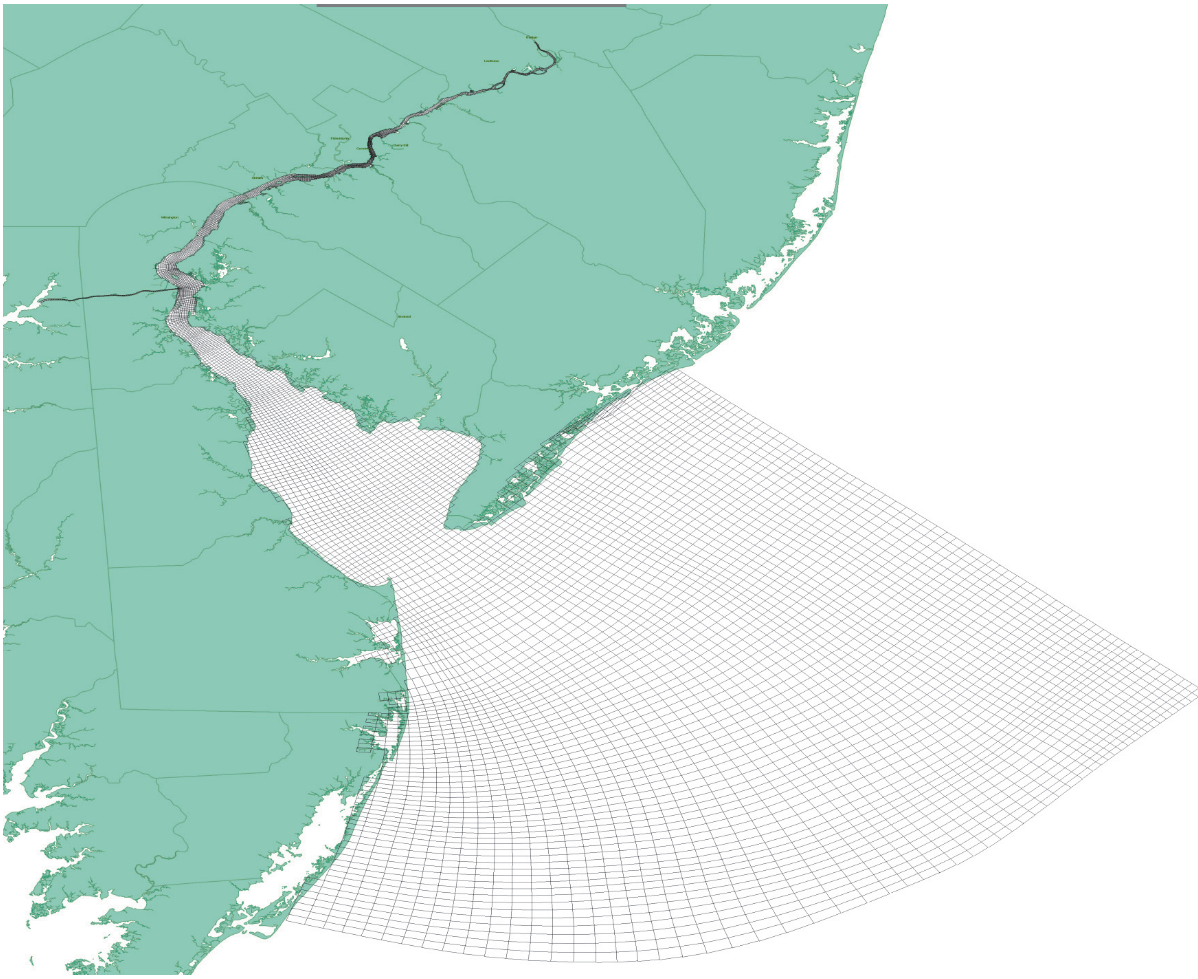


Figure 2.1. National Ocean Service DBOFS ROMS computational grid.

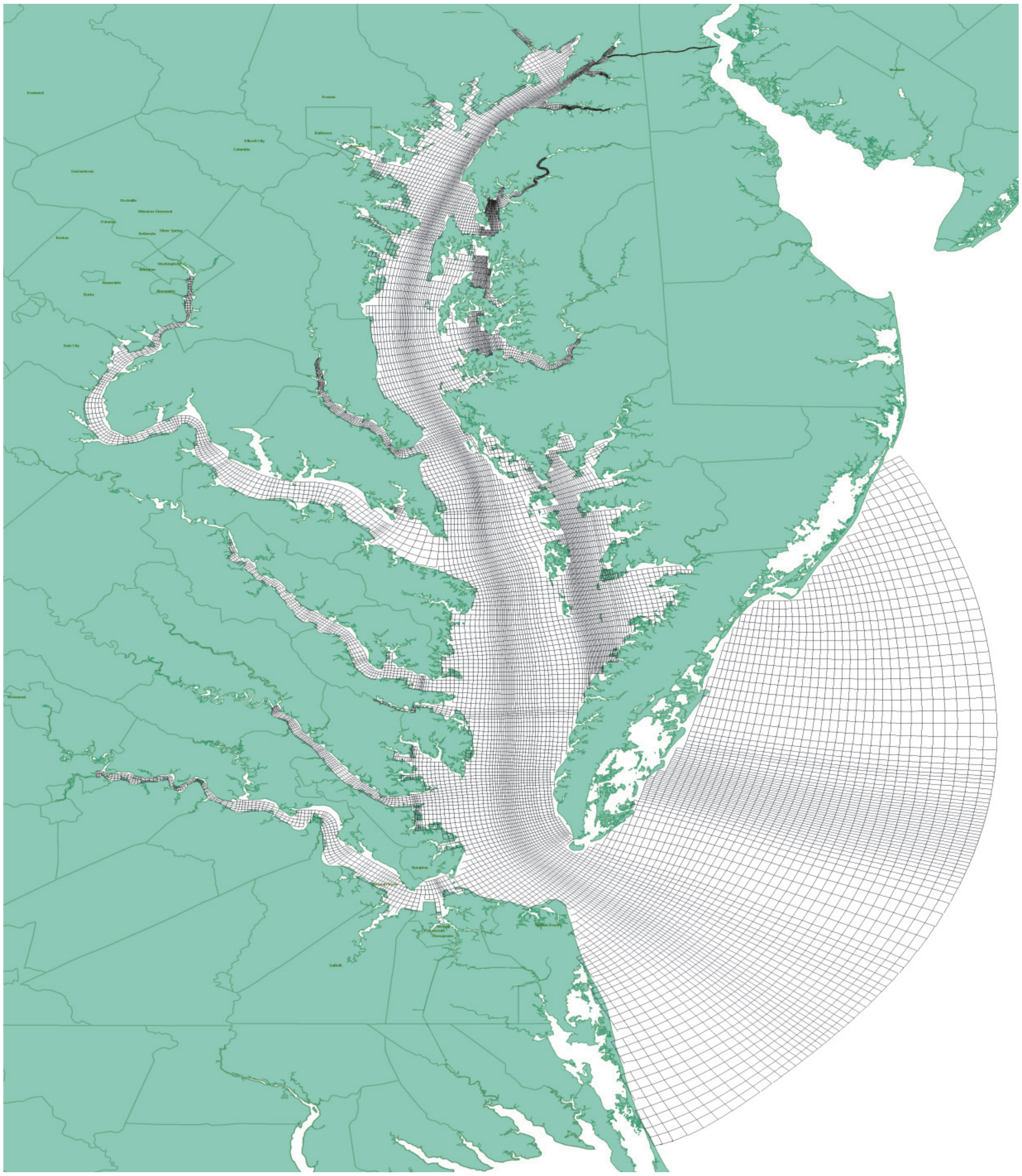


Figure 2.2. National Ocean Service CBOFS ROMS computational grid.

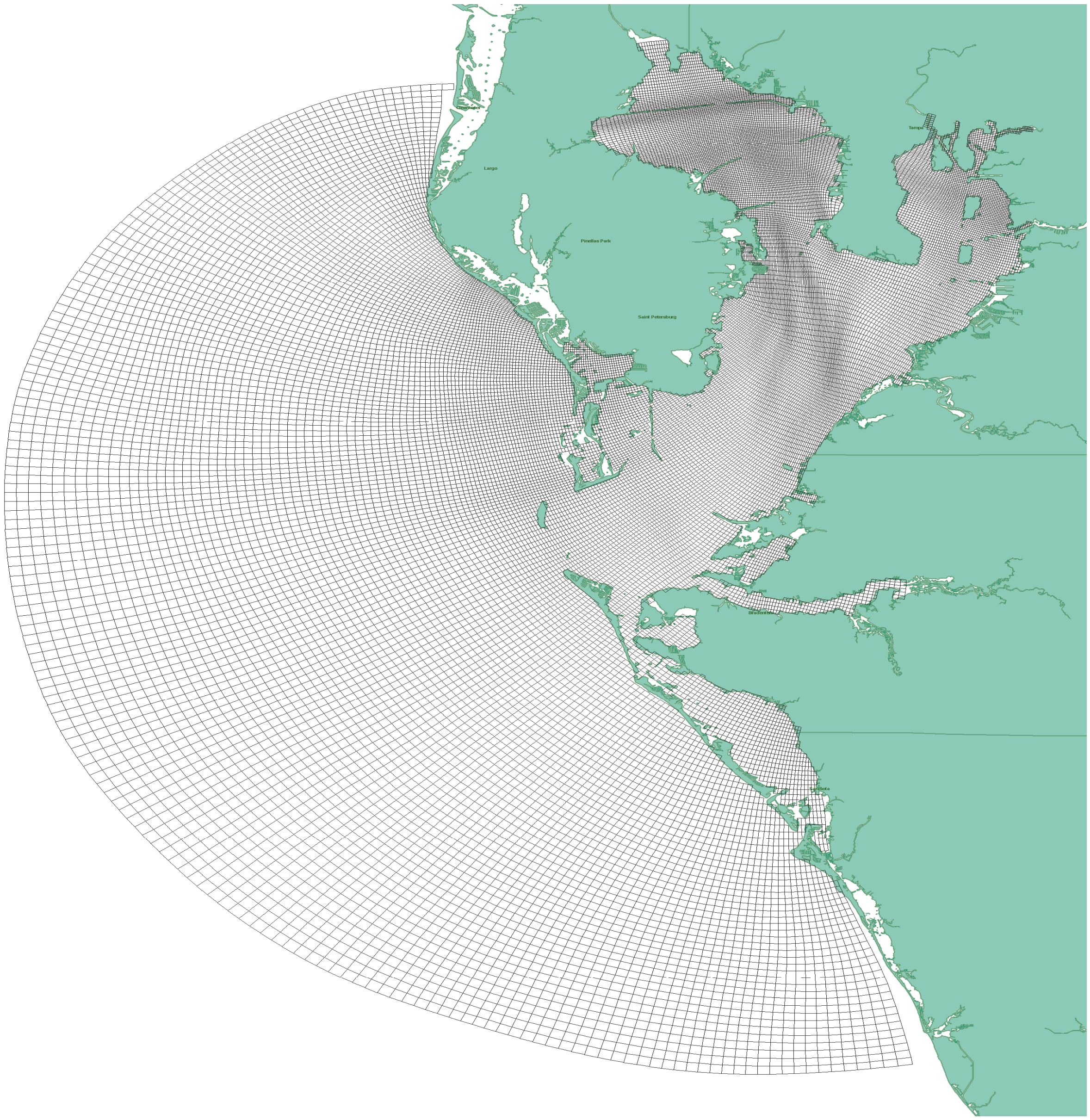


Figure 2.3. National Ocean Service TBOFS ROMS computational grid.

Table 2.3. Salinity Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Comparisons are made at every 10th grid point of each OFS.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.58 2.96	0.10 0.57	32.87 35.39	32.42 32.44
DBOFS	30 30	0.62 2.65	0.06 0.48	33.27 35.39	32.79 32.81
DBOFS	81 81	0.79 2.01	0.07 0.34	34.05 35.35	33.40 33.52
CBOFS	0 0	0.65 3.51	0.46 0.87	32.19 35.43	31.68 31.99
CBOFS	15 17	0.64 3.21	0.33 0.83	32.50 35.56	31.95 32.78
CBOFS	36 39	1.16 2.88	0.60 0.84	33.38 35.56	32.52 32.78
TBOFS	0 0	0.20 0.74	0.71 0.90	35.33 34.83	35.39 35.34
TBOFS	10 10	0.24 0.80	0.42 0.64	35.35 34.87	35.50 35.51
TBOFS	20 22	0.26 0.97	0.25 0.75	35.61 34.91	35.71 35.74

Table 2.4. Water Temperature Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th grid point of each OFS.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	1.42 0.98	0.52 0.28	17.64 18.25	18.93 18.81
DBOFS	30 30	1.45 3.24	0.18 0.84	16.48 18.33	17.42 17.30
DBOFS	81 81	1.99 4.89	0.13 0.60	14.17 17.81	14.38 14.04
CBOFS	0 0	1.45 1.43	0.65 0.54	18.33 18.30	19.67 19.62
CBOFS	15 17	1.60 1.33	0.61 0.50	18.14 18.37	19.58 19.52
CBOFS	36 39	2.61 1.36	0.49 0.57	16.83 18.36	18.68 18.28
TBOFS	0 0	0.17 0.83	0.13 0.60	26.42 25.78	26.55 26.48
TBOFS	10 10	0.49 0.73	0.53 0.67	26.01 25.86	26.45 26.37
TBOFS	20 22	0.31 0.73	0.55 0.86	26.03 25.90	26.20 26.06

Table 2.5. U (East) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	5.14 11.77	0.44 0.80	6.71 14.43	1.00 1.00	5.59 0.13	4.12 4.12	9.17 9.17
DBOFS	30 30	5.71 11.33	0.47 0.78	4.43 13.30	0.82 0.97	8.92 2.30	4.12 4.12	9.01 9.01
DBOFS	81 81	3.17 10.94	0.31 0.65	3.79 13.36	0.52 0.82	5.79 0.65	4.12 4.12	8.37 8.33
CBOFS	0 0	6.73 15.49	0.73 0.78	4.22 15.72	1.00 1.00	1.82 3.12	6.62 7.27	4.75 4.75
CBOFS	15 17	3.98 11.58	0.32 0.74	5.58 13.20	1.00 0.99	8.76 10.50	6.62 7.27	4.78 4.79
CBOFS	36 39	4.36 10.48	0.38 0.71	5.62 12.85	0.97 1.00	8.65 13.09	6.62 7.27	4.73 4.72
TBOFS	0 0	2.32 12.18	0.50 0.91	2.22 12.23	1.00 1.00	3.07 11.42	2.39 2.19	1.74 1.74
TBOFS	10 10	2.01 11.46	0.52 0.90	1.78 11.63	0.96 0.99	2.97 11.36	2.39 2.19	1.70 1.70
TBOFS	20 22	5.20 11.20	0.76 0.89	5.45 11.47	0.99 0.99	6.54 11.60	2.39 2.19	1.61 1.60

Table 2.6. V (North) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 10/20/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	3.29 11.55	0.64 0.87	4.41 13.07	1.00 1.00	1.96 -4.40	3.30 3.30	5.29 5.29
DBOFS	30 30	2.97 11.36	0.66 0.86	4.60 13.14	0.93 0.97	1.27 -4.94	3.30 3.30	5.53 5.53
DBOFS	81 81	2.88 11.22	0.67 0.88	4.37 13.03	0.91 0.97	1.56 -5.83	3.30 3.30	5.42 5.40
CBOFS	0 0	3.26 6.72	0.59 0.90	4.15 6.45	1.00 1.00	0.00 -0.05	2.82 3.04	4.15 4.15
CBOFS	15 17	1.82 6.28	0.22 0.84	3.73 6.59	0.91 0.93	1.50 -0.13	2.82 3.04	4.65 4.70
CBOFS	36 39	2.69 6.84	0.32 0.86	2.92 7.69	0.88 0.98	4.24 -0.66	2.82 3.04	5.13 5.18
TBOFS	0 0	7.54 6.19	0.86 0.86	9.29 5.24	1.00 1.00	8.26 -2.53	1.29 1.15	-0.73 -0.73
TBOFS	10 10	4.88 5.17	0.89 0.84	6.24 4.06	0.98 0.97	4.75 -2.22	1.29 1.15	-0.81 -0.82
TBOFS	20 22	3.68 6.77	0.90 0.89	4.91 5.91	0.97 0.97	3.32 -1.99	1.29 1.15	-0.89 -0.90

estimate. The ADCIRC velocity components are placed along the NOS OFS open boundaries on the ocean model water grid and depth correspondence to the OFS boundary cell. As a result, the ADCIRC velocity components in Table 2.5 and 2.6 are different for G-NCOM and RTOFS for CBOFS and TBOFS. These issues should be kept in mind in the subsequent chapters.

3. NOVEMBER 2010 MONTHLY ANALYSIS

During November 2010, both the G-NCOM and RTOFS ocean model 00 UTC nowcast/forecast cycles were accessed to provide daily snapshots on November 9 and 10, 2010**.** Both cycles were analyzed with the results for both daily snapshots being very similar. As a result, we show here the results for November 9th only**.**

In Table 3.1 for water temperature and in Table 3.2 for salinity, the two ocean model predictions are compared with the TESAC CTD profiles at three locations. It should be noted, that the purpose of these comparisons is to provide an initial spot check on the integrity of the ocean model vertical density structure. Within the analysis only every 10th CTD profile is considered. In Figures 3.1 – 3.3, the salinity profile comparisons are shown, while in Figures 3.4-3.6, the water temperature profile comparisons are plotted. Note the stratification index shown in the figures corresponds to Stratification Index One. In general, the comparisons are reasonable except at Station 44062, which is located at the Patuxent River, NAS, mid-way up the Chesapeake Bay, where lack of grid resolution may be a factor.

In Table 3.3, the ocean model salinity responses along the three NOS OFS boundaries are presented. The analysis considers every 10th ocean model boundary point. Note for DBOFS, CBOFS, and TBOFS the number of boundary points is 128, 106, and 176, respectively. The responses are compared relative to the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 3.7 (DBOFS), Figure 3.8 (CBOFS), and in Figure 3.9 (TBOFS), the surface salinity ocean model responses corresponded closely to climatology with one exception. The RTOFS forecast tended to exceed climatology by 2 to 3 PSU along the DBOFS open boundary, unlike the G-NCOM surface salinity response, which was very near climatology. Near bottom salinity comparisons were similar to the surface comparisons except along the DBOFS and CBOFS open boundaries, with RTOFS again above climatology by 2 PSU and G-NCOM very near climatology.

In Table 3.4, the ocean model water temperature responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 3.10 (DBOFS), Figure 3.11 (CBOFS), and in Figure 3.12 (TBOFS), the surface water temperature ocean model responses corresponded closely to climatology with one exception. The RTOFS forecast tended to exceed climatology by 2 to 3 ^{o}C along the DBOFS open boundary, unlike the G-NCOM surface water temperature response, which was very near climatology. Near bottom water temperature comparisons are not shown, but are very similar except along the DBOFS open boundary, with

RTOFS again above climatology by 4 ^{o}C along some sections of the boundary and G-NCOM very near climatology throughout.

In Table 3.5, the ocean model U (East) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity may be different due to the different model depths and the difference in correspondence of the ocean model grid points to the OFS boundary grid points. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in Figure 3.13 (DBOFS), Figure 3.14 (CBOFS), and in Figure 3.15 (TBOFS), the surface U (East) velocity component ocean model responses are quite different along the DBOFS and CBOFS open boundaries. Note in these figures, the G-NCOM comparison to WOA 2001 climatology is labeled Levitus and the RTOFS forecast comparison is to the ADCIRC vertically integrated velocity component.

In Table 3.6, the ocean model V (North) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity may be different due to the different model depths and the difference in correspondence of the ocean model grid points to the OFS boundary grid points. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in Figure 3.16 (DBOFS), Figure 3.17 (CBOFS), and in Figure 3.18 (TBOFS), the surface V (North) velocity component ocean model responses are quite different along all three OFS open boundaries. Note in these figures, the G-NCOM comparison to WOA 2001 climatology is labeled Levitus and the RTOFS forecast comparison is to the ADCIRC vertically integrated velocity component.

Table 3.1. Water Temperature (^oC) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data November 2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC-ATL=South Carolina Atlantic, MD-CB=Maryland Chesapeake Bay, FL-GM=Florida Gulf of Mexico.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033 SC-ATL	11/9:0	12 20	3.66 2.75	18.49 19.98	20.35 23.47	19.14 20.09	22.22 21.65	1.21 1.71	0.06 0.08
44062 MD-CB	11:9/0	6 20	0.86 4.95	12.69 12.97	14.18 12.23	12.96 13.12	12.40 22.90	1.51 10.52	0.11 0.60
42013 FL-GM	11/9:0	35 30	1.19 1.72	23.97 23.46	23.70 23.70	24.33 23.55	25.19 25.19	1.13 1.39	0.05 0.06

Table 3.2. Salinity (PSU) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data November 2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC-ATL=South Carolina Atlantic, MD-CB=Maryland Chesapeake Bay, FL-GM=Florida Gulf of Mexico.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033 SC-ATL	11/9:0	12 20	0.49 0.83	35.51 36.93	35.35 36.16	35.60 36.94	36.12 36.01	0.68 0.14	0.02 0.00
44062 MD-CB	11/9:0	6 20	11.38 12.20	28.83 8.28	14.10 18.78	28.87 8.46	21.02 21.17	6.88 2.20	0.39 0.11
42013 FL-GM	11/9:0	35 30	0.32 0.13	35.65 35.39	35.23 35.23	35.95 35.39	35.53 35.53	0.00 0.30	0.00 0.01

Table 3.3. Salinity Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 11/9/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Comparisons are made at every 10th grid point of each OFS.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.66 2.90	0.13 0.57	32.90 35.51	32.69 32.72
DBOFS	30 30	0.64 2.67	0.07 0.51	33.21 35.51	33.00 33.02
DBOFS	81 81	0.68 2.12	0.05 0.41	33.95 35.49	33.58 33.71
CBOFS	0 0	0.65 3.24	0.38 0.84	32.46 35.46	31.93 32.24
CBOFS	15 17	0.58 3.04	0.29 0.82	32.54 35.46	32.05 32.44
CBOFS	36 39	1.00 2.48	0.48 0.81	33.22 35.47	32.80 33.04
TBOFS	0 0	0.28 0.27	0.49 0.38	35.49 35.23	35.24 35.15
TBOFS	10 10	0.20 0.22	0.24 0.18	35.49 35.23	35.31 35.26
TBOFS	20 22	0.11 0.32	0.08 0.35	35.51 35.23	35.47 35.44

Table 3.4. Water Temperature Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 11/9/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th grid point of each OFS.

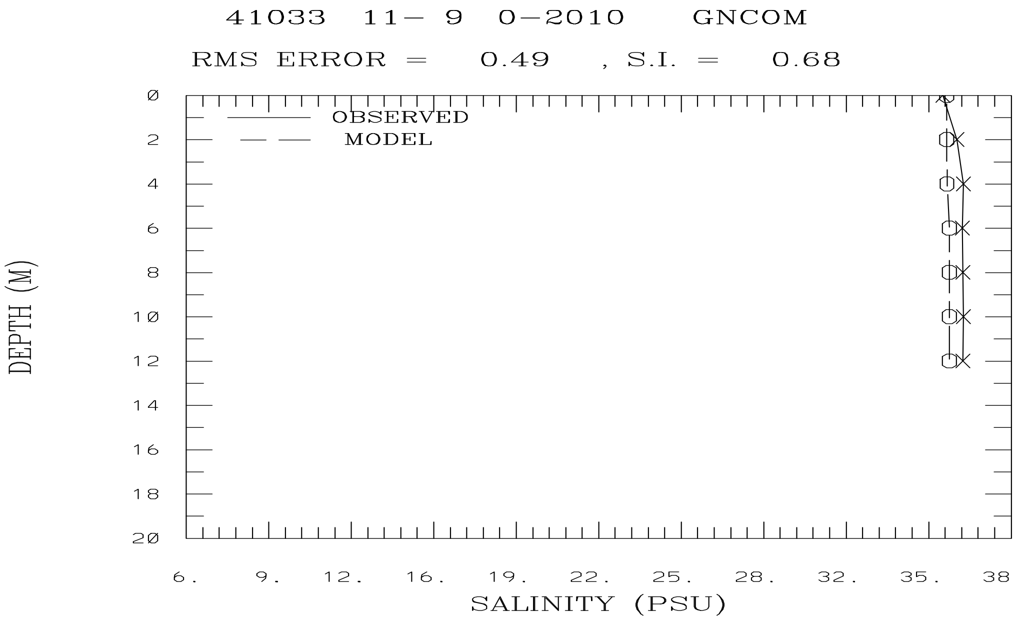
NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.82 1.08	0.17 0.20	14.49 15.59	15.11 14.99
DBOFS	30 30	0.76 1.88	0.17 0.43	14.26 15.63	14.66 14.56
DBOFS	81 81	1.01 2.97	0.10 0.76	13.16 15.43	13.38 13.43
CBOFS	0 0	0.81 0.99	0.30 0.33	15.14 15.00	15.83 15.86
CBOFS	15 17	0.75 1.03	0.27 0.32	15.27 15.03	15.92 15.92
CBOFS	36 39	1.01 0.98	0.59 0.36	15.31 15.04	16.11 15.93
TBOFS	0 0	0.67 0.49	0.34 0.52	23.39 23.35	23.85 23.58
TBOFS	10 10	0.67 0.47	0.33 0.45	23.42 23.42	23.88 23.64
TBOFS	20 22	0.70 0.57	0.33 0.52	23.50 23.43	24.00 23.79

Table 3.5. U (East) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 11/9/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	29.90 37.63	0.85 0.89	31.40 38.84	1.00 1.00	-19.98 -21.81	7.68 7.68	10.49 10.49
DBOFS	30 30	32.00 31.26	0.88 0.87	32.95 32.13	0.99 1.00	-20.49 -11.51	7.68 7.68	10.26 10.26
DBOFS	81 81	20.75 21.33	0.75 0.78	22.15 22.75	0.95 0.96	-11.43 -9.36	7.68 7.68	9.59 9.56
CBOFS	0 0	24.64 51.68	0.82 0.93	16.74 42.79	1.00 1.00	-10.66 -36.90	12.62 13.80	5.23 5.23
CBOFS	15 17	31.56 45.02	0.87 0.93	23.46 36.05	1.00 0.99	-17.29 -26.97	12.62 13.80	5.23 5.23
CBOFS	36 39	27.60 39.60	0.84 0.93	19.54 30.37	0.99 0.99	-13.59 -24.07	12.62 13.80	5.06 5.05
TBOFS	0 0	5.68 6.74	0.81 0.75	6.39 5.92	1.00 1.00	7.29 -1.25	2.46 2.44	1.26 1.26
TBOFS	10 10	5.72 7.23	0.81 0.79	6.52 7.17	0.99 0.99	7.36 3.89	2.46 2.44	1.19 1.18
TBOFS	20 22	6.12 7.05	0.81 0.82	7.06 7.56	0.99 0.99	7.74 6.54	2.46 2.44	1.07 1.06

Table 3.6. V (North) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 11/9/2010. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	34.09 34.29	0.84 0.86	32.06 32.32	1.00 1.00	-25.94 -23.27	6.31 6.31	4.15 4.15
DBOFS	30 30	13.90 21.00	0.77 0.78	11.21 20.03	0.99 0.99	-5.04 -5.69	6.31 6.31	4.27 4.27
DBOFS	81 81	5.45 8.20	0.31 0.54	6.21 7.96	0.88 0.92	4.75 4.00	6.31 6.31	4.19 4.18
CBOFS	0 0	33.95 38.78	0.89 0.92	29.42 32.86	1.00 1.00	-23.44 -30.61	6.70 7.07	1.13 1.13
CBOFS	15 17	16.34 17.17	0.80 0.87	11.64 12.29	0.99 0.97	-8.63 -7.78	6.70 7.07	1.56 1.60
CBOFS	36 39	7.24 9.53	0.62 0.76	3.82 7.29	0.95 0.98	0.49 0.75	6.70 7.07	2.00 2.04
TBOFS	0 0	17.55 33.63	0.85 0.91	14.04 30.17	1.00 1.00	-13.91 -29.22	2.91 2.99	-0.30 -0.30
TBOFS	10 10	16.33 28.50	0.84 0.90	12.81 25.11	1.00 1.00	-12.70 -23.73	2.91 2.99	-0.31 -0.31
TBOFS	20 22	15.56 26.04	0.83 0.89	12.02 22.59	1.00 1.00	-11.93 -21.29	2.91 2.99	-0.33 -0.33



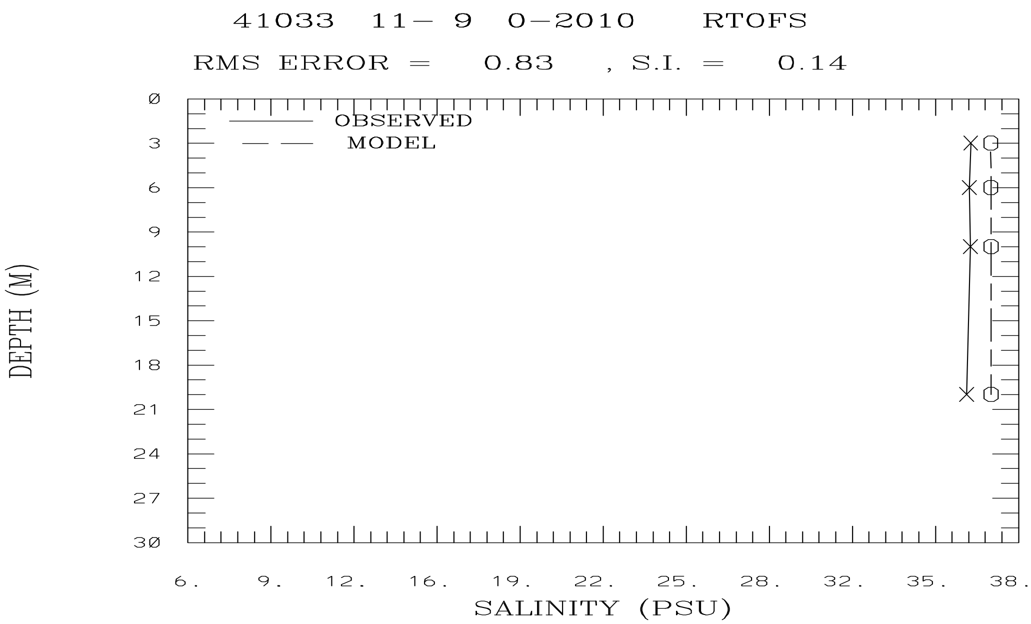
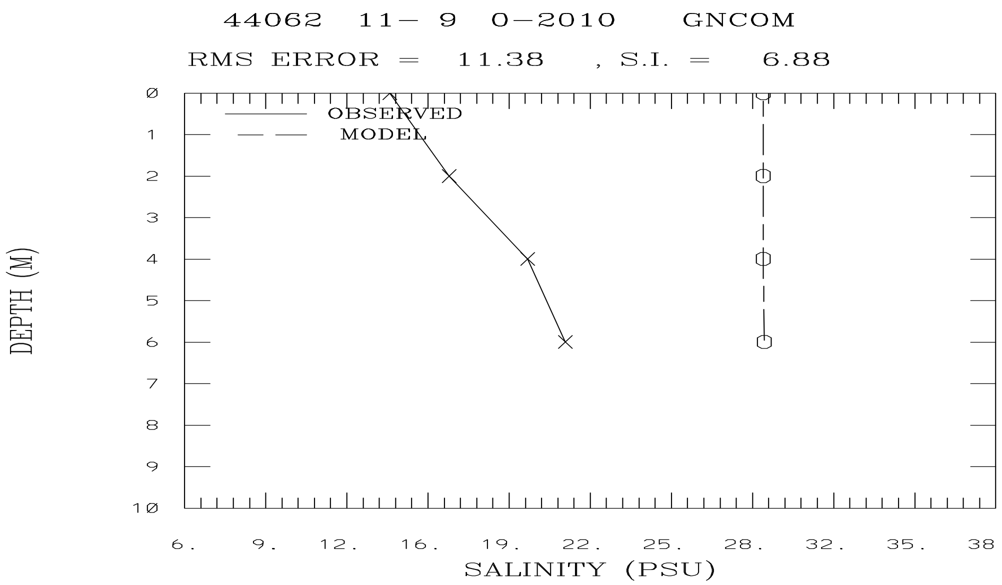


Figure 3.1. G-NCOM and RTOFS salinity forecast profile at Station 41033: data versus model comparisons on November 9, 2010 at hour 00 UTC.



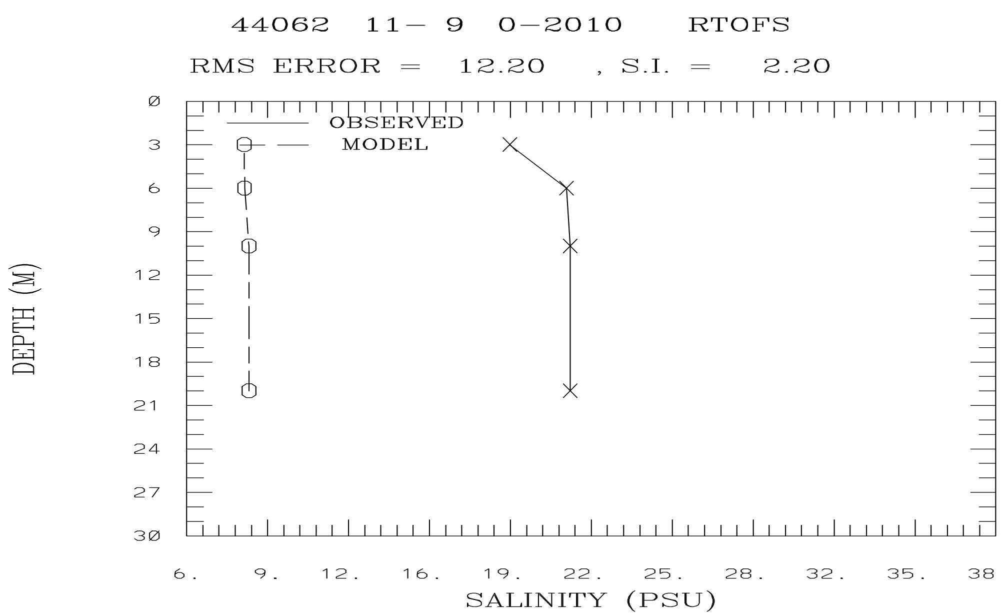
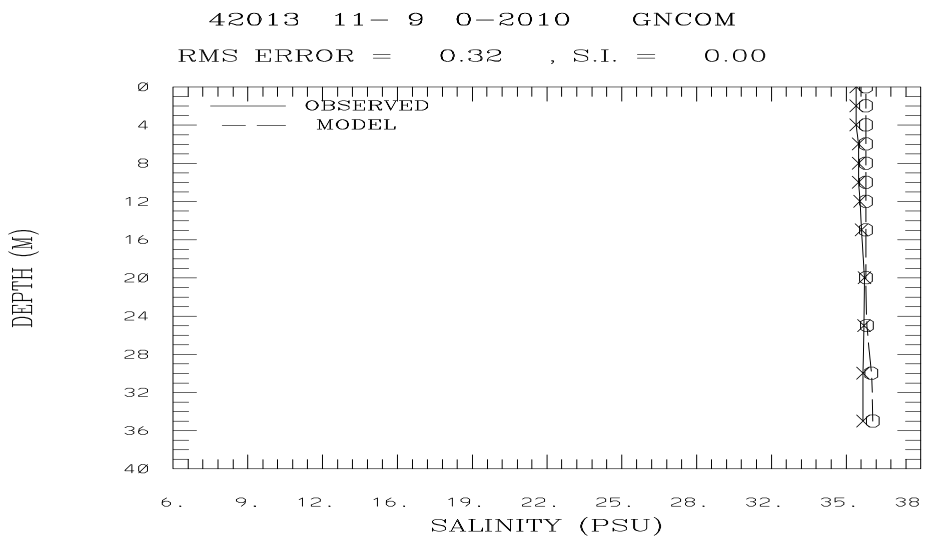


Figure 3.2. G-NCOM and RTOFS salinity forecast profile at Station 44062: data versus model comparisons on November 9, 2010 at hour 00 UTC.



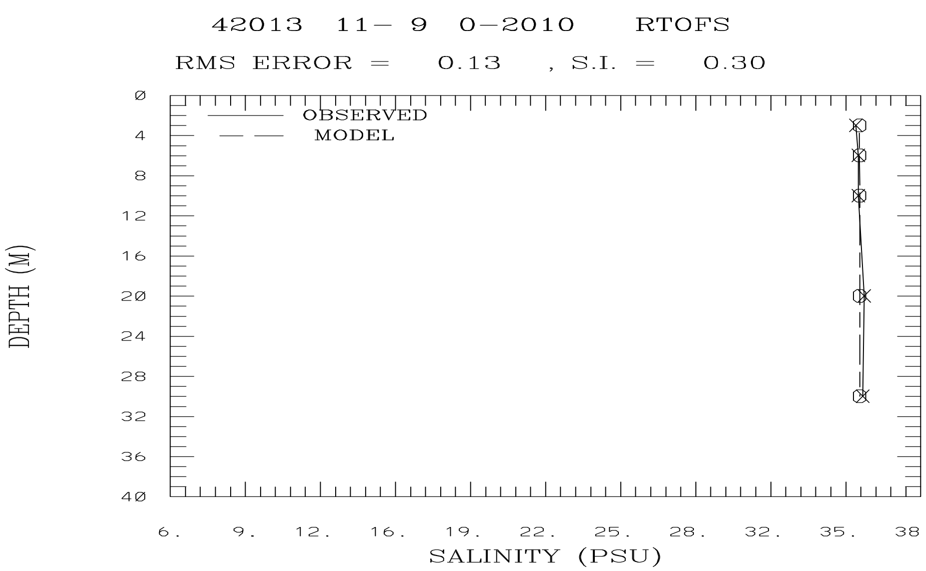
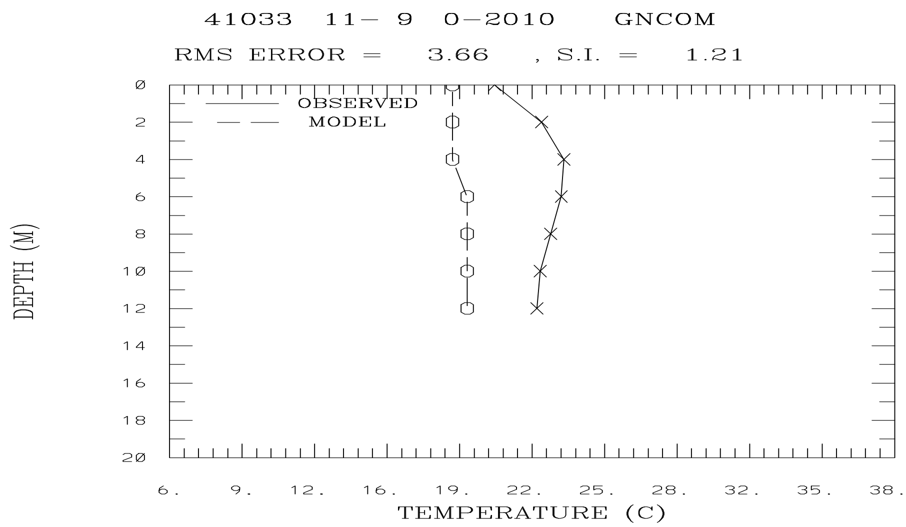


Figure 3.3. G-NCOM and RTOFS salinity forecast profile at Station 42013: data versus model comparisons on November 9, 2010 at hour 00 UTC.



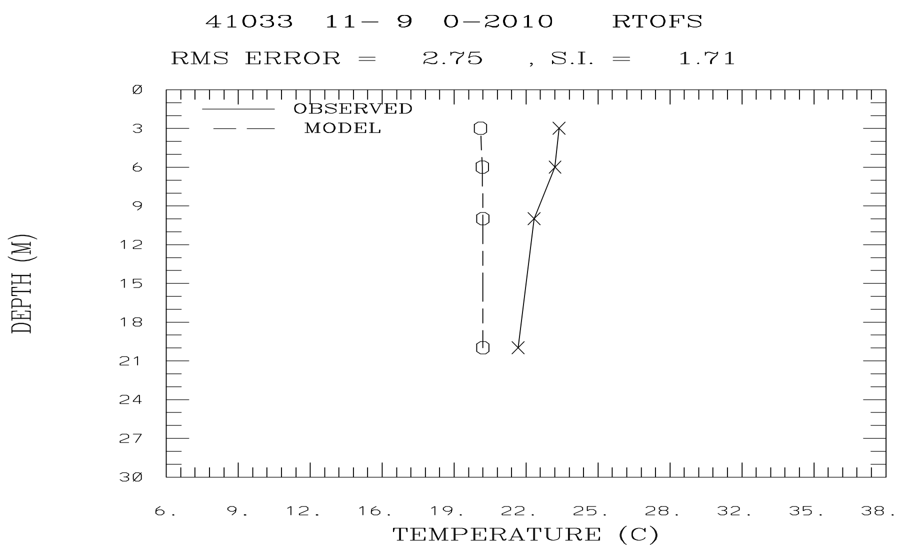
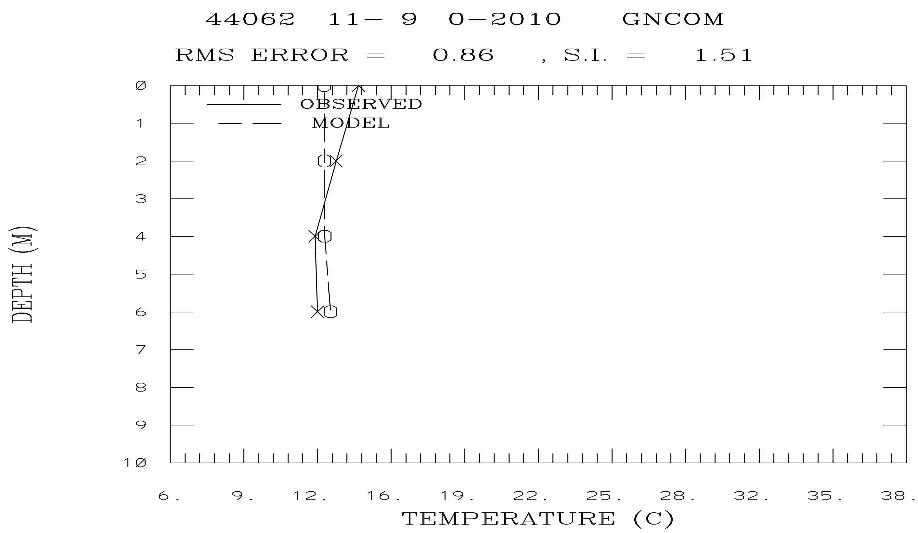


Figure 3.4. G-NCOM and RTOFS water temperature forecast profile at Station 41033: data versus model comparisons on November 9, 2010 at hour 00 UTC.



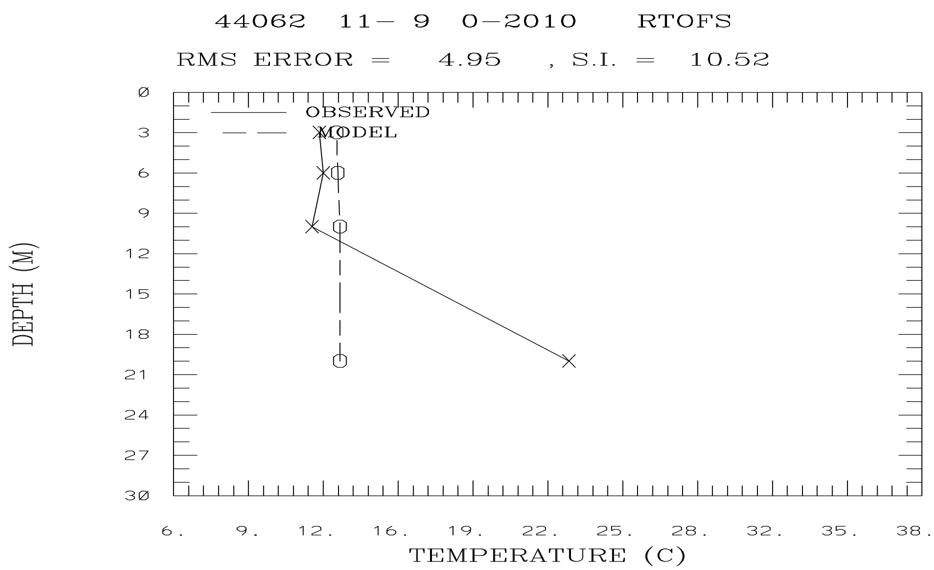
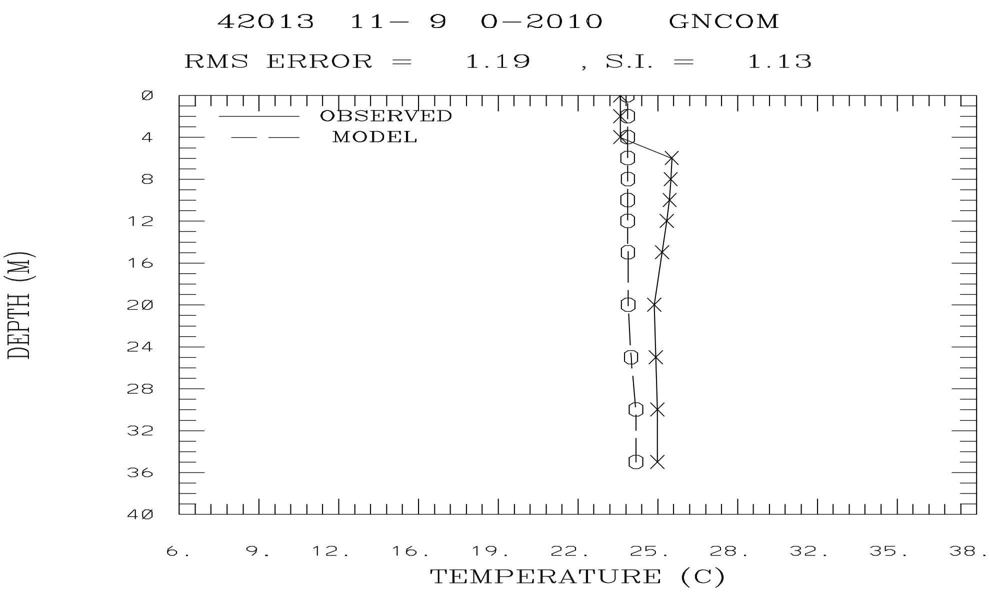


Figure 3.5. G-NCOM and RTOFS water temperature forecast profile at Station 44062: data versus model comparisons on November 9, 2010 at hour 00 UTC.



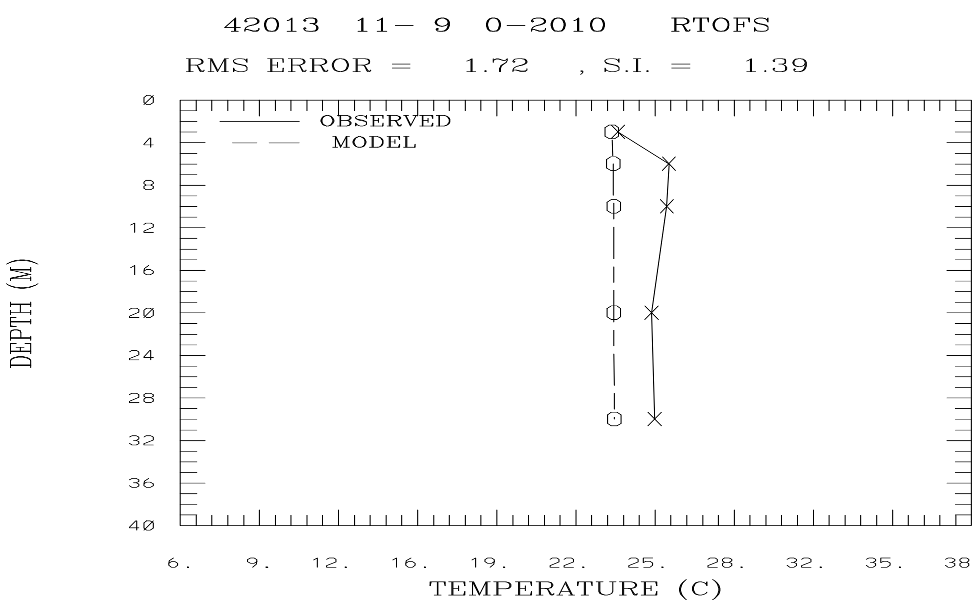


Figure 3.6. G-NCOM and RTOFS water temperature forecast profile at Station 42013: data versus model comparisons on November 9, 2010 at hour 00 UTC.

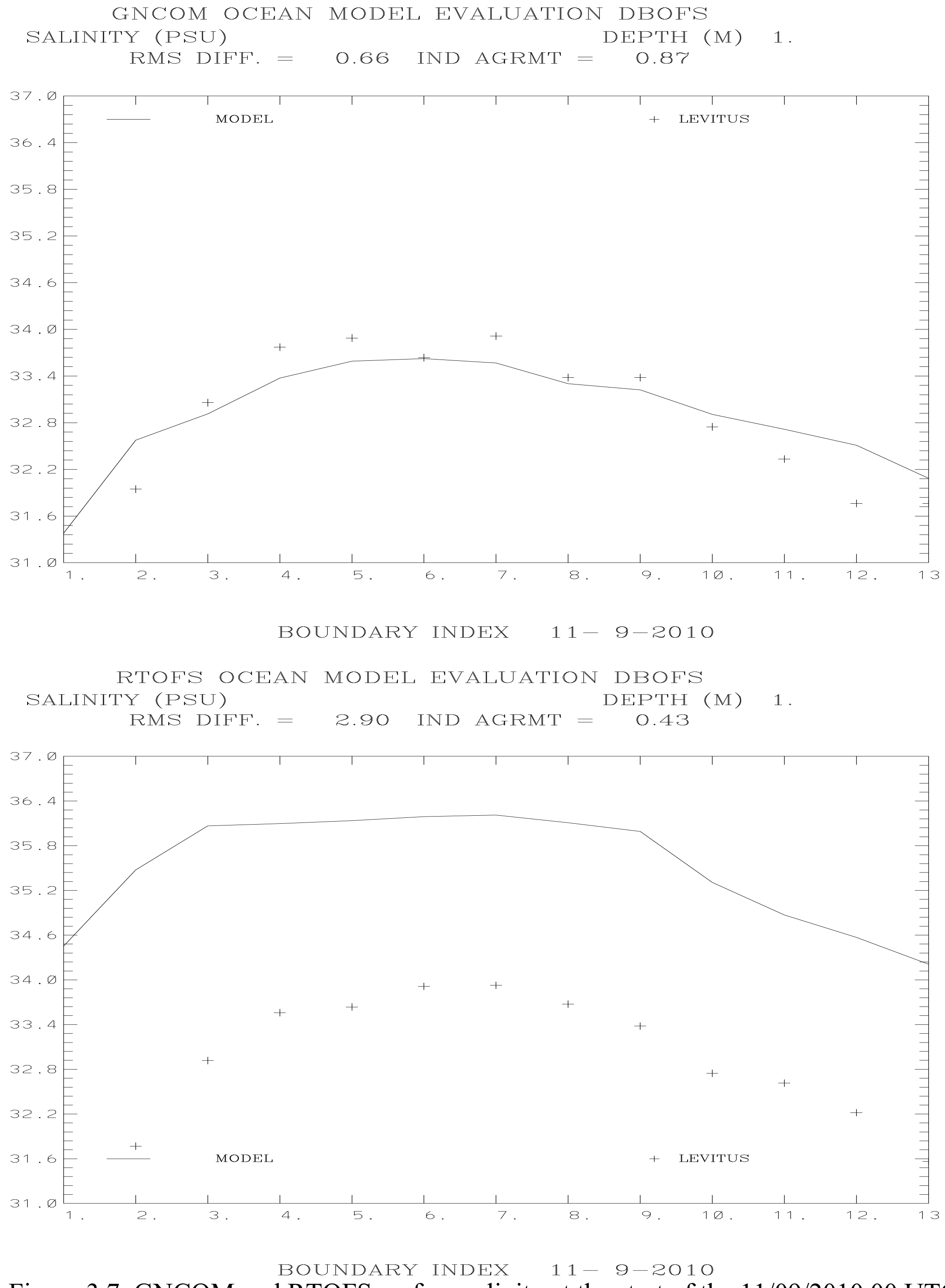
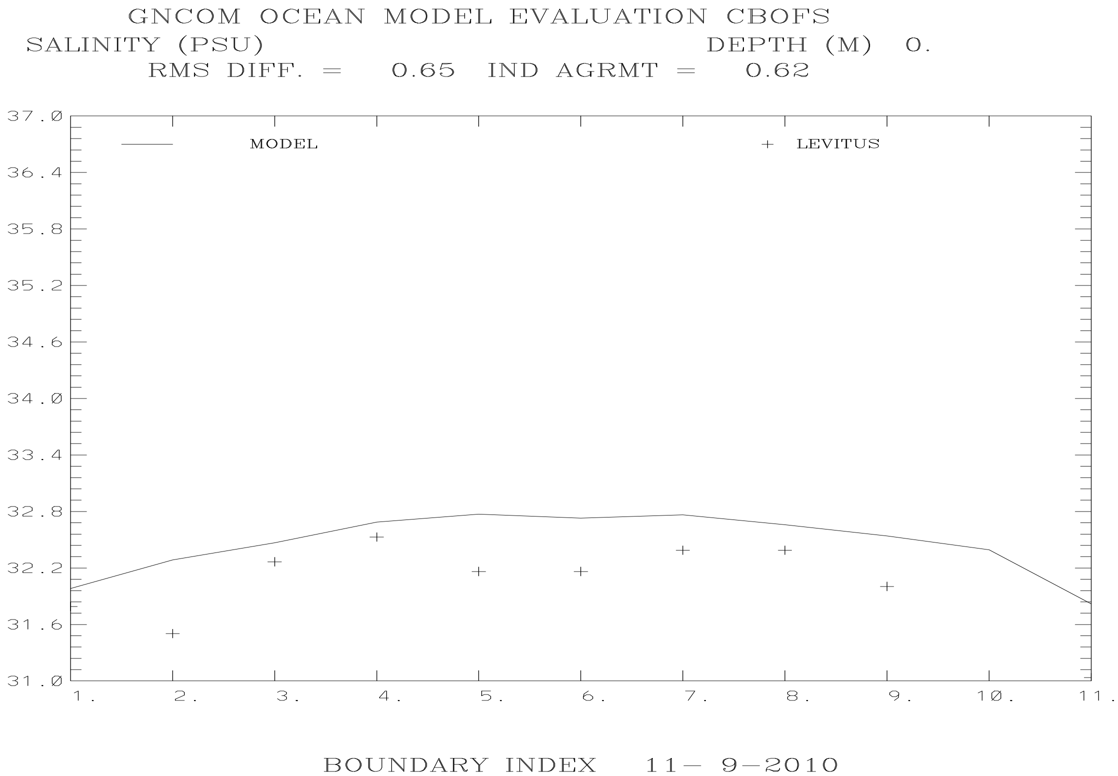


Figure 3.7. GNCOM and RTOFS surface salinity at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



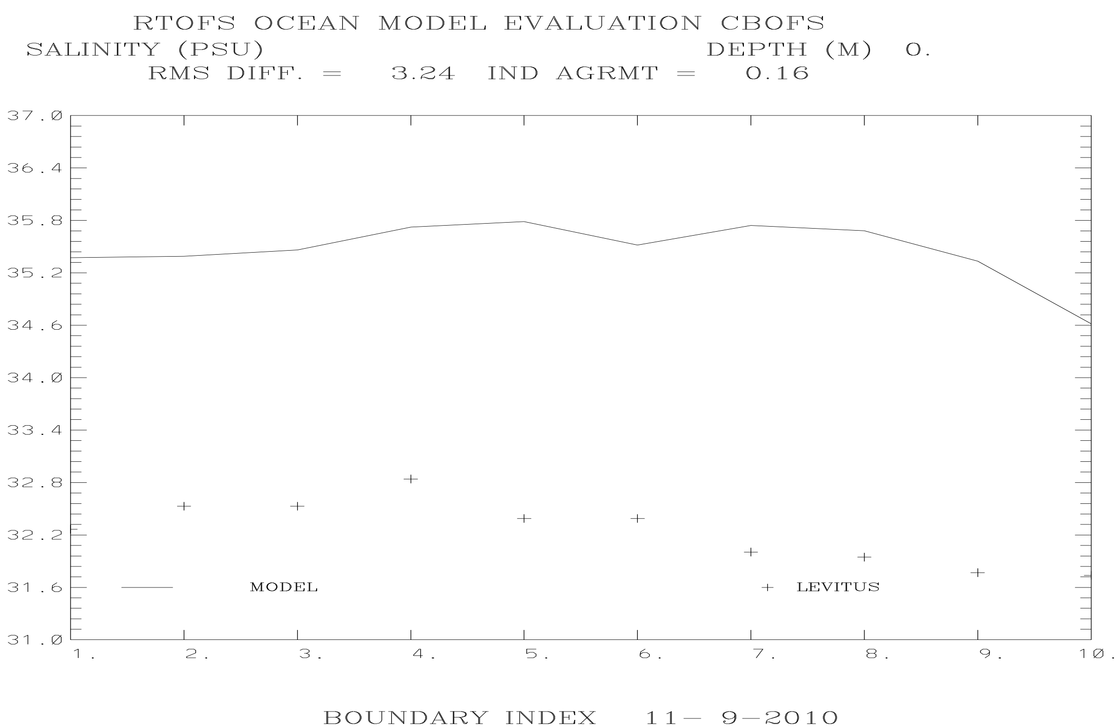
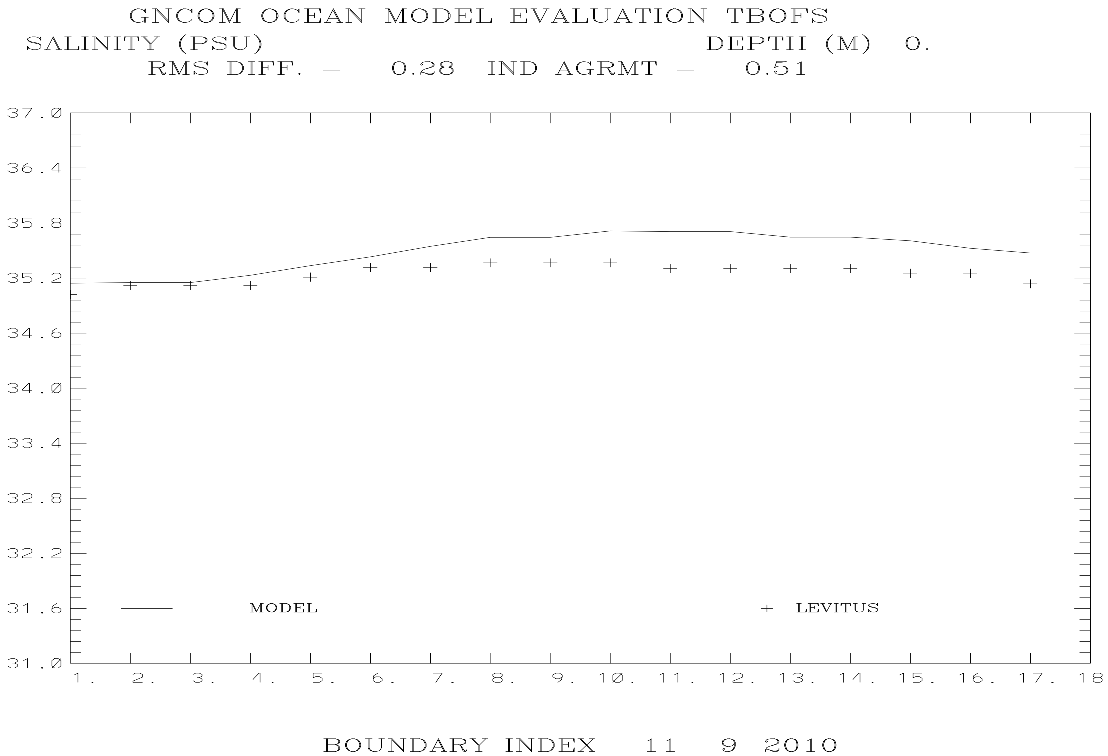


Figure 3.8. GNCOM and RTOFS surface salinity at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



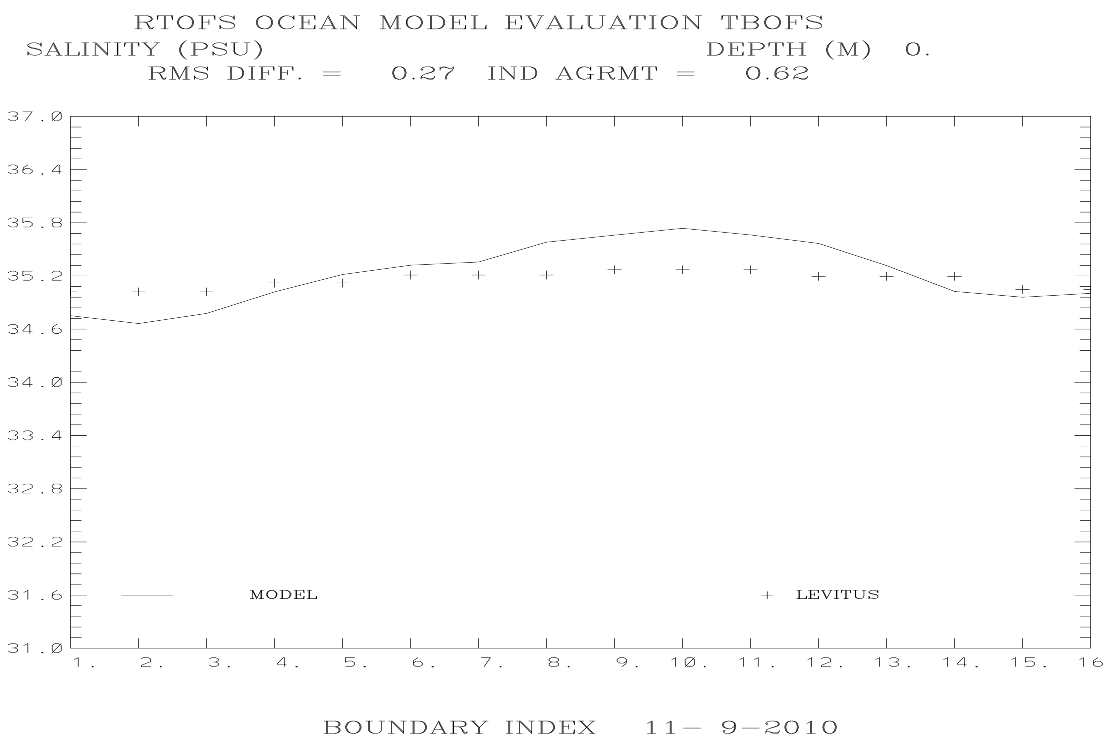
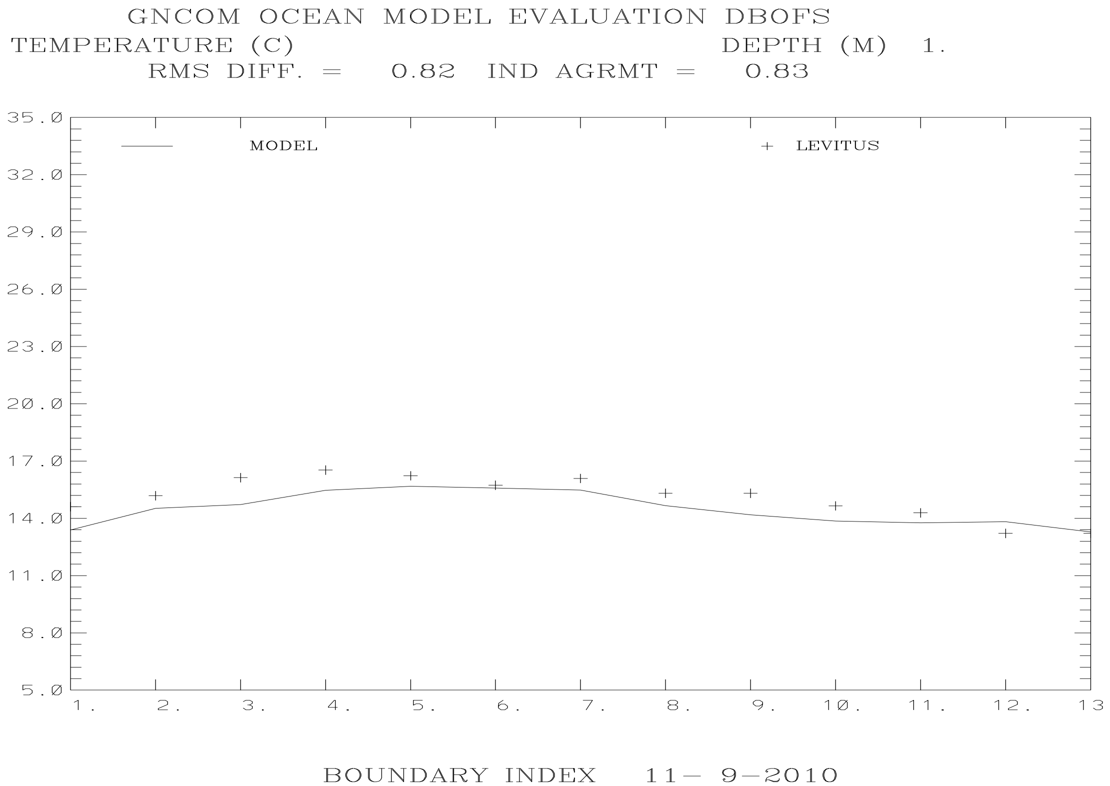


Figure 3.9. GNCOM and RTOFS surface salinity at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.



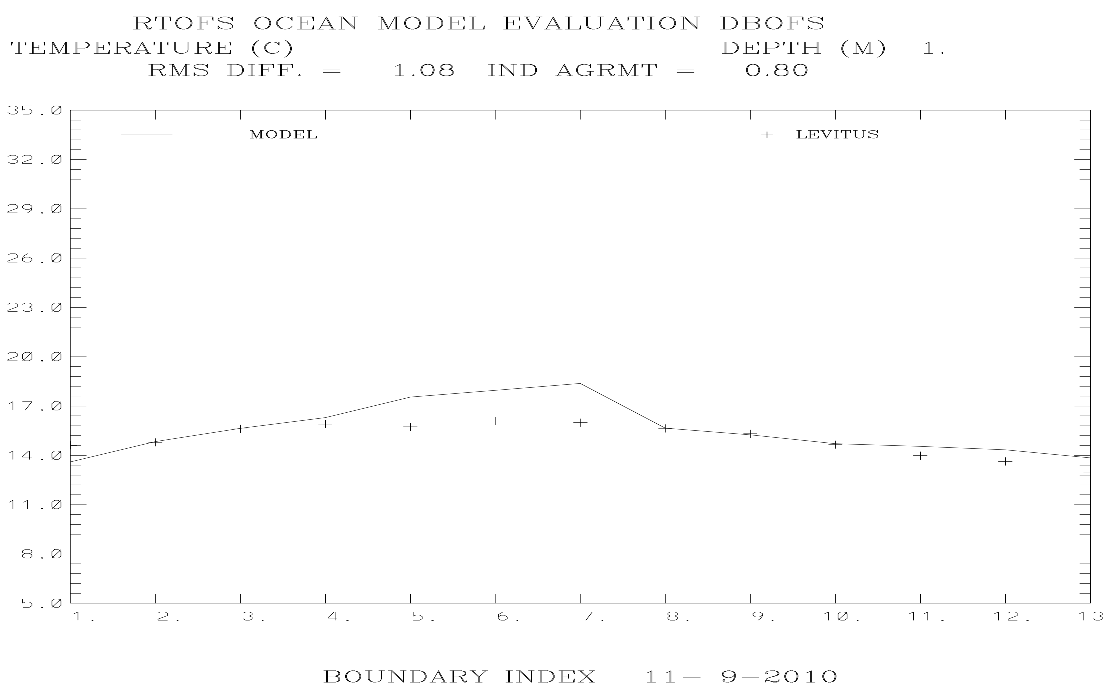
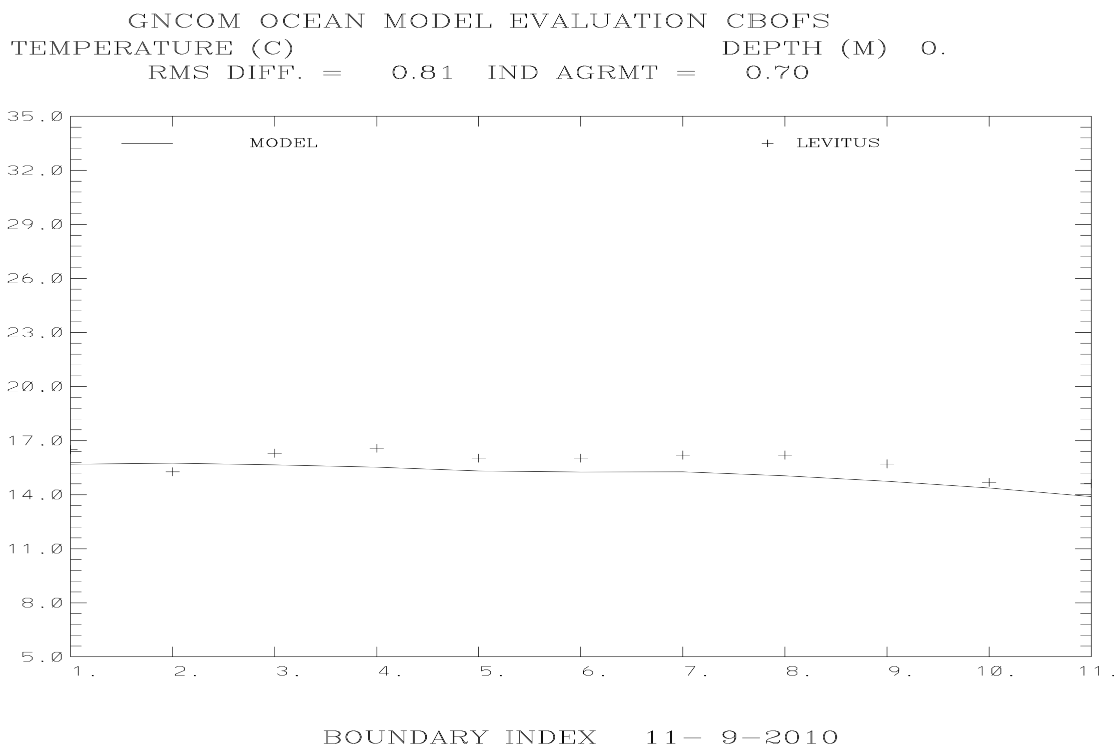


Figure 3.10. GNCOM and RTOFS surface water temperature at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



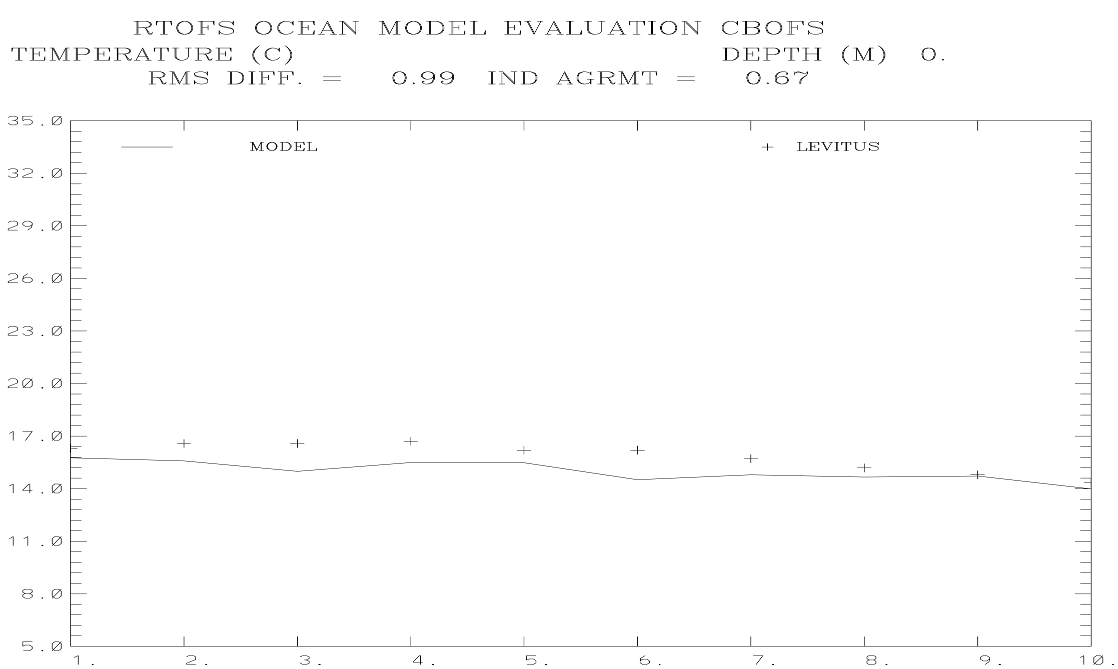
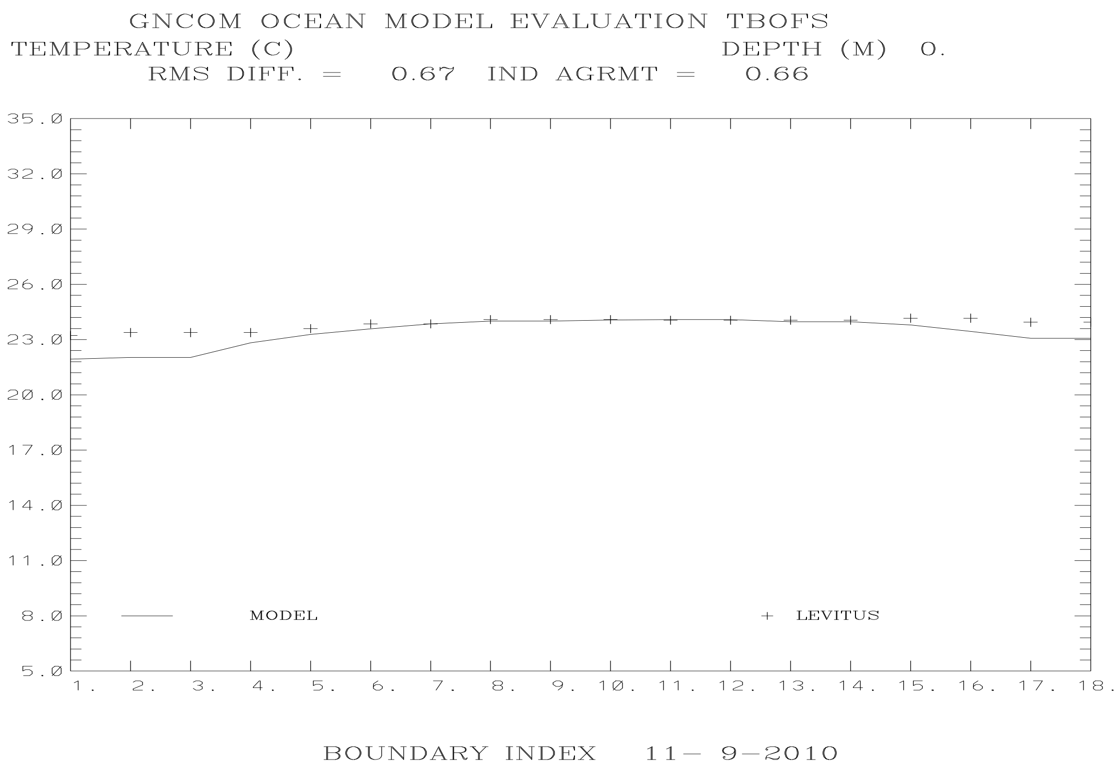


Figure 3.11. GNCOM and RTOFS surface water temperature at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



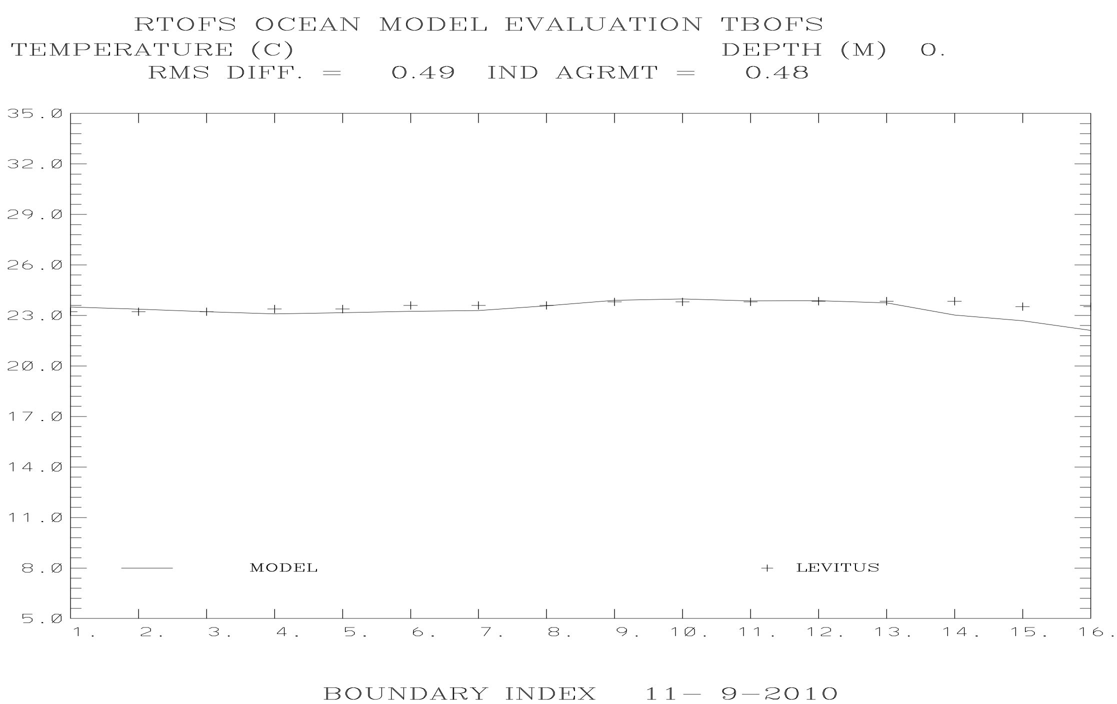
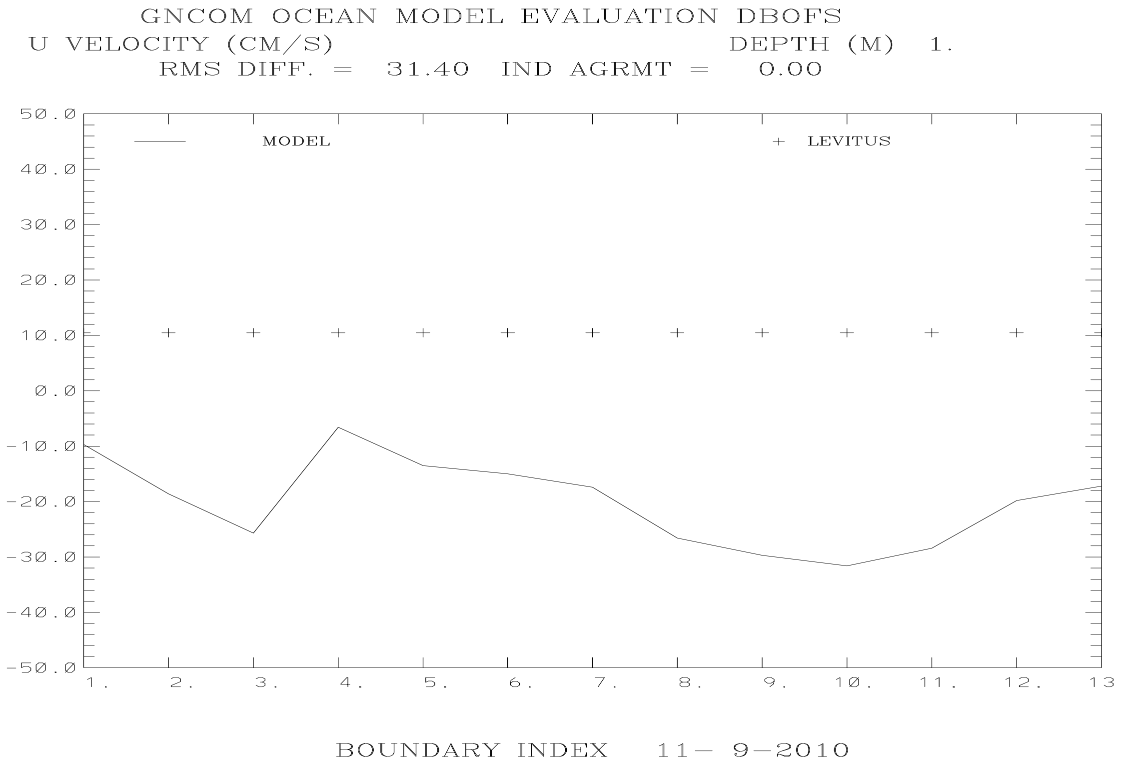


Figure 3.12. GNCOM and RTOFS surface water temperature at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology at every 10^{th} grid point along the TBOFS open boundary.



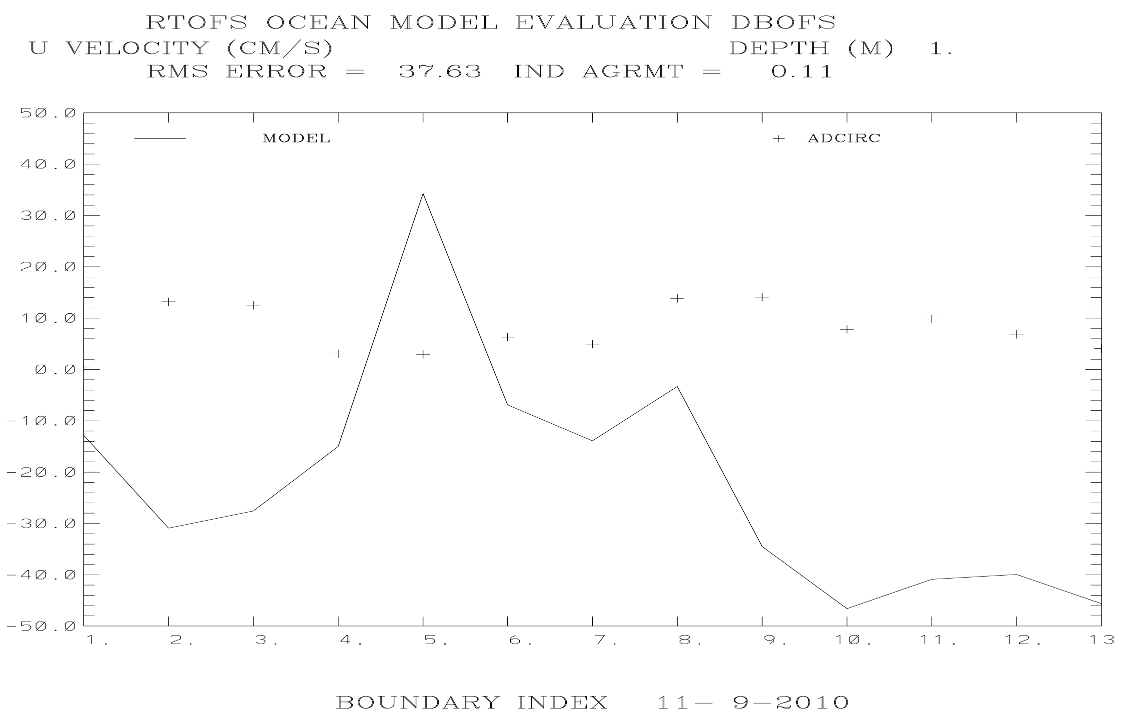
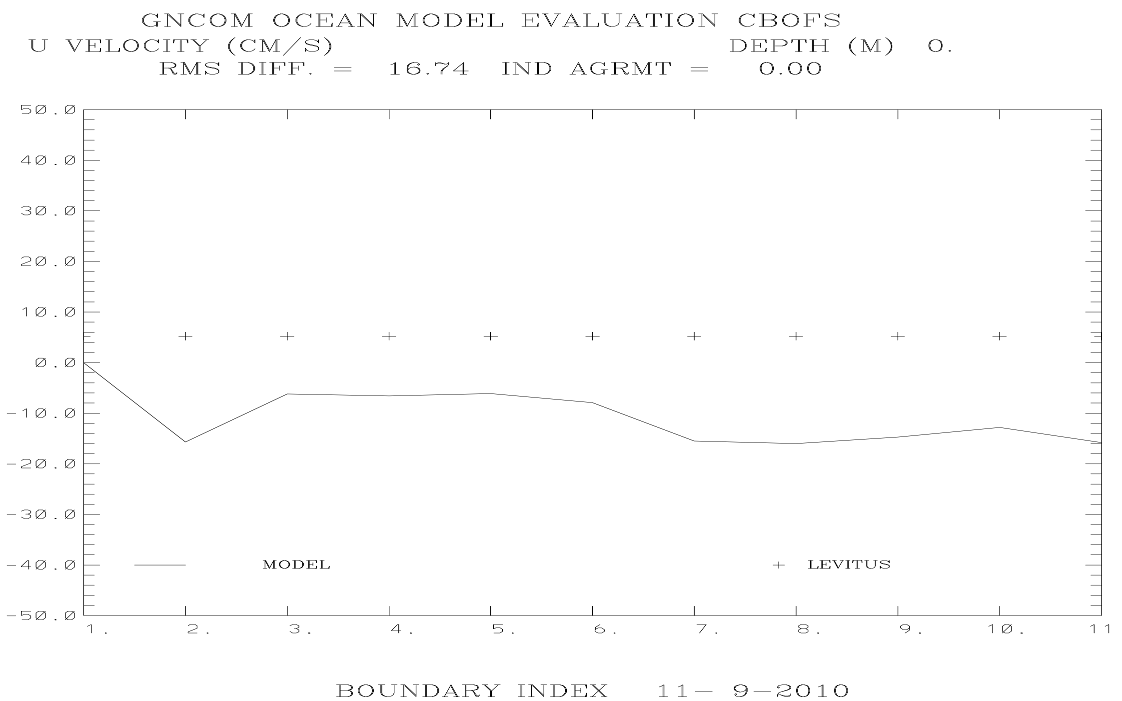


Figure 3.13. GNCOM and RTOFS surface U (East) velocity component at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the DBOFS open boundary.



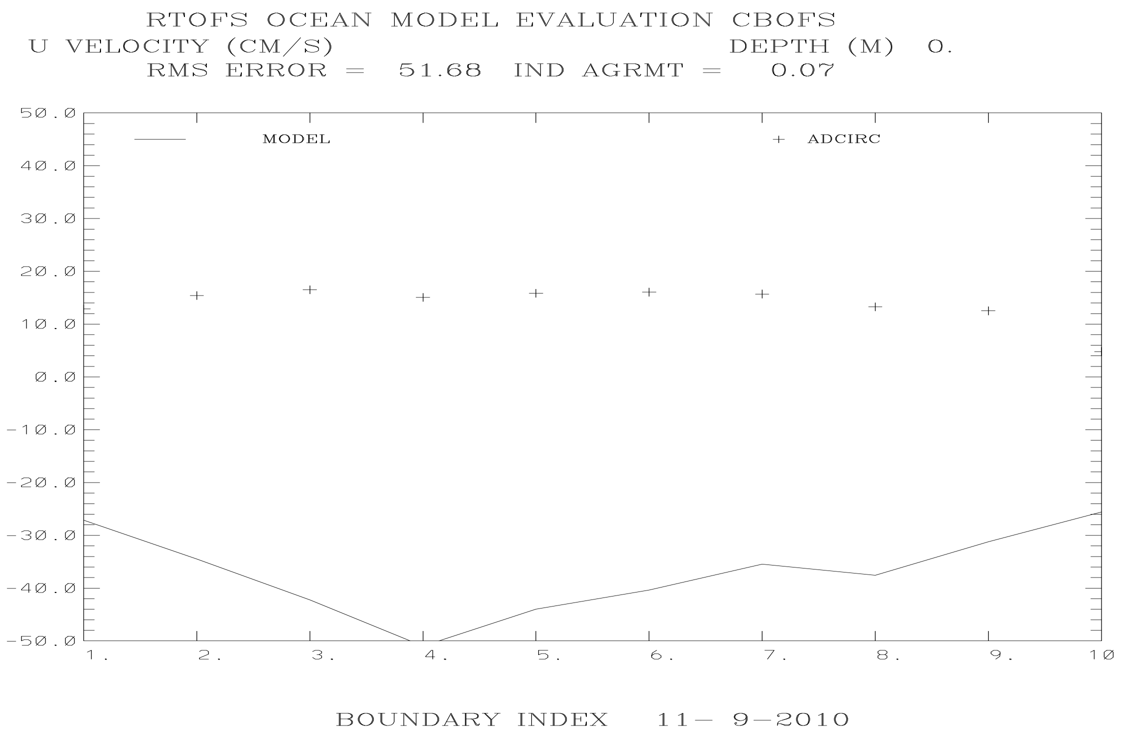
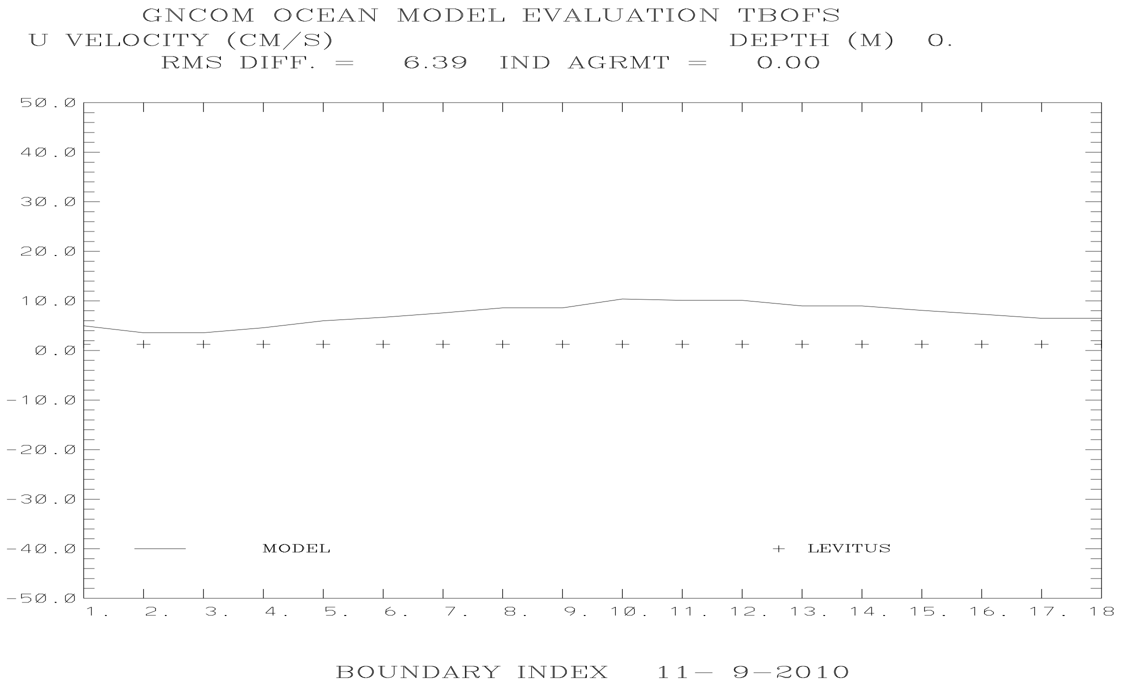


Figure 3.14. GNCOM and RTOFS surface U (East) velocity component at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the CBOFS open boundary.



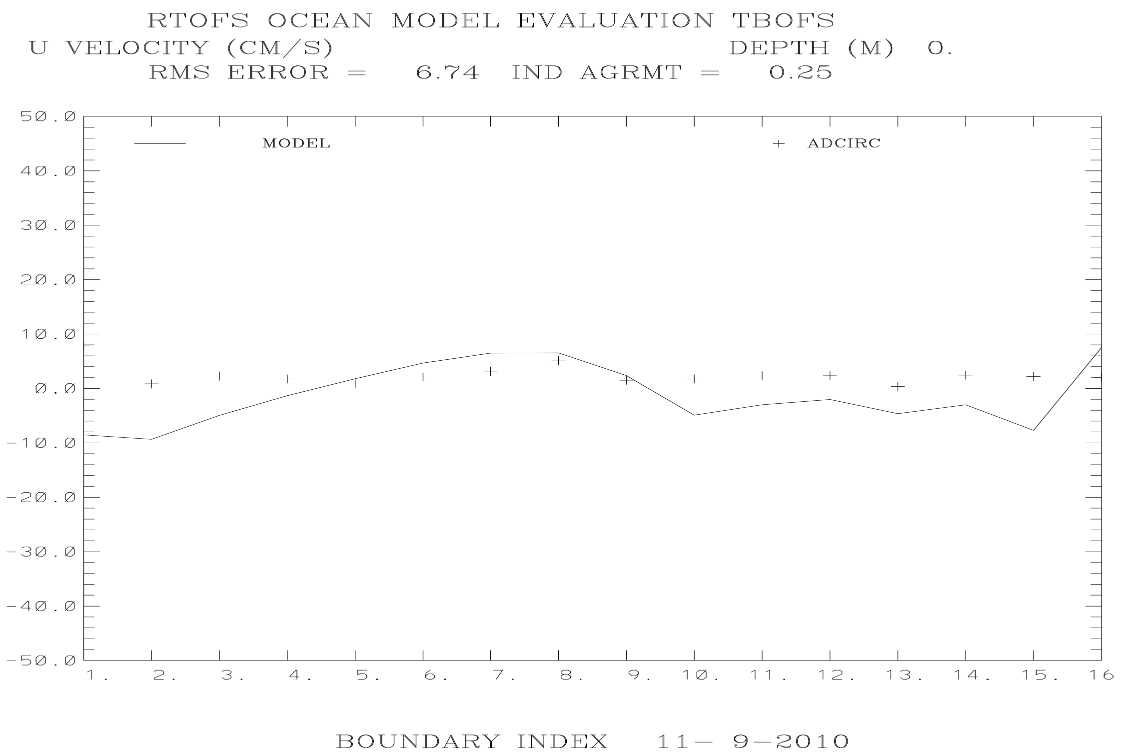
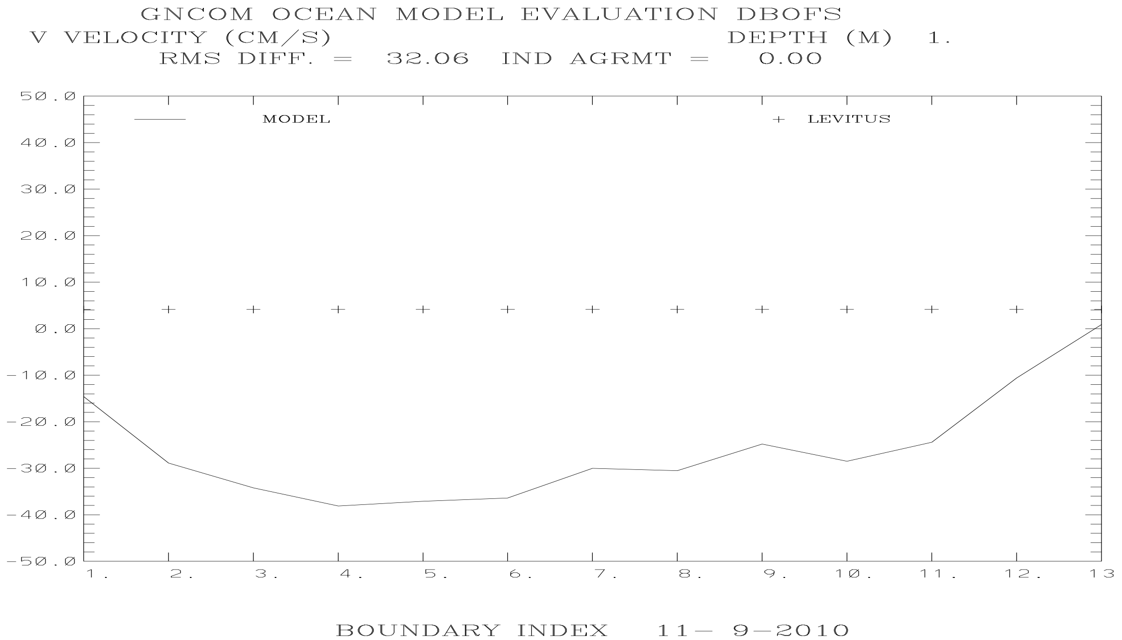


Figure 3.15. GNCOM and RTOFS surface U (East) velocity component at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10^{th} grid point along the TBOFS open boundary.



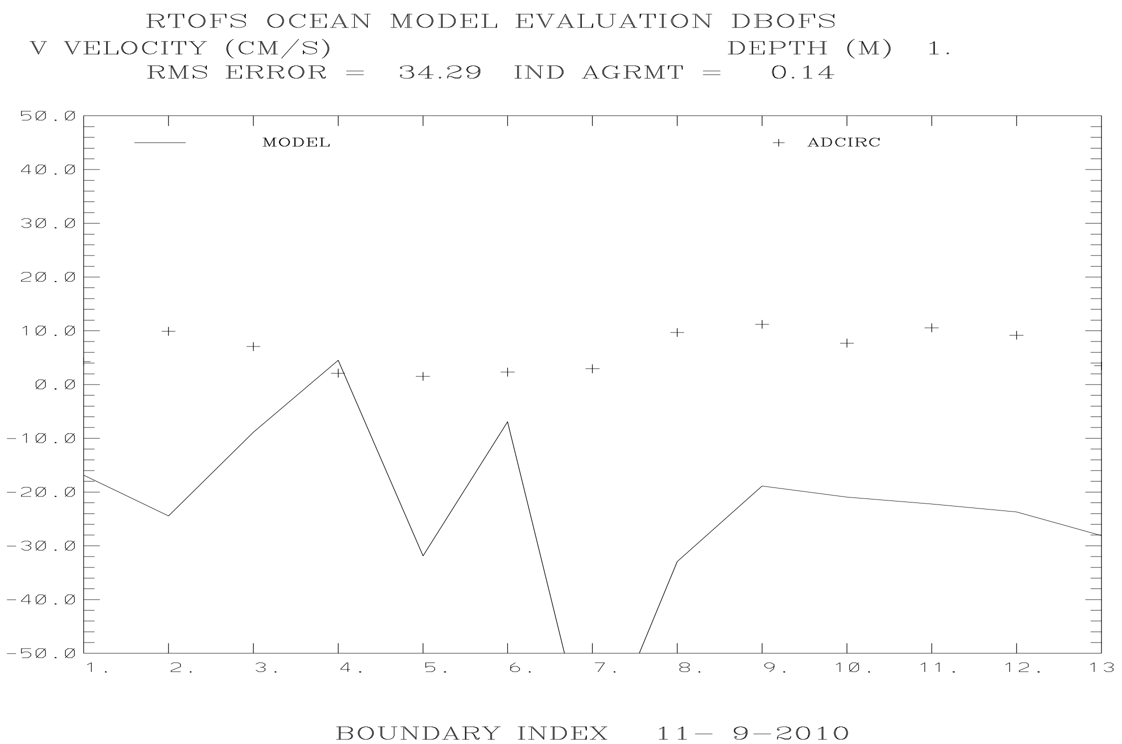


Figure 3.16. GNCOM and RTOFS surface V (North) velocity component at the start of the 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the DBOFS open boundary.

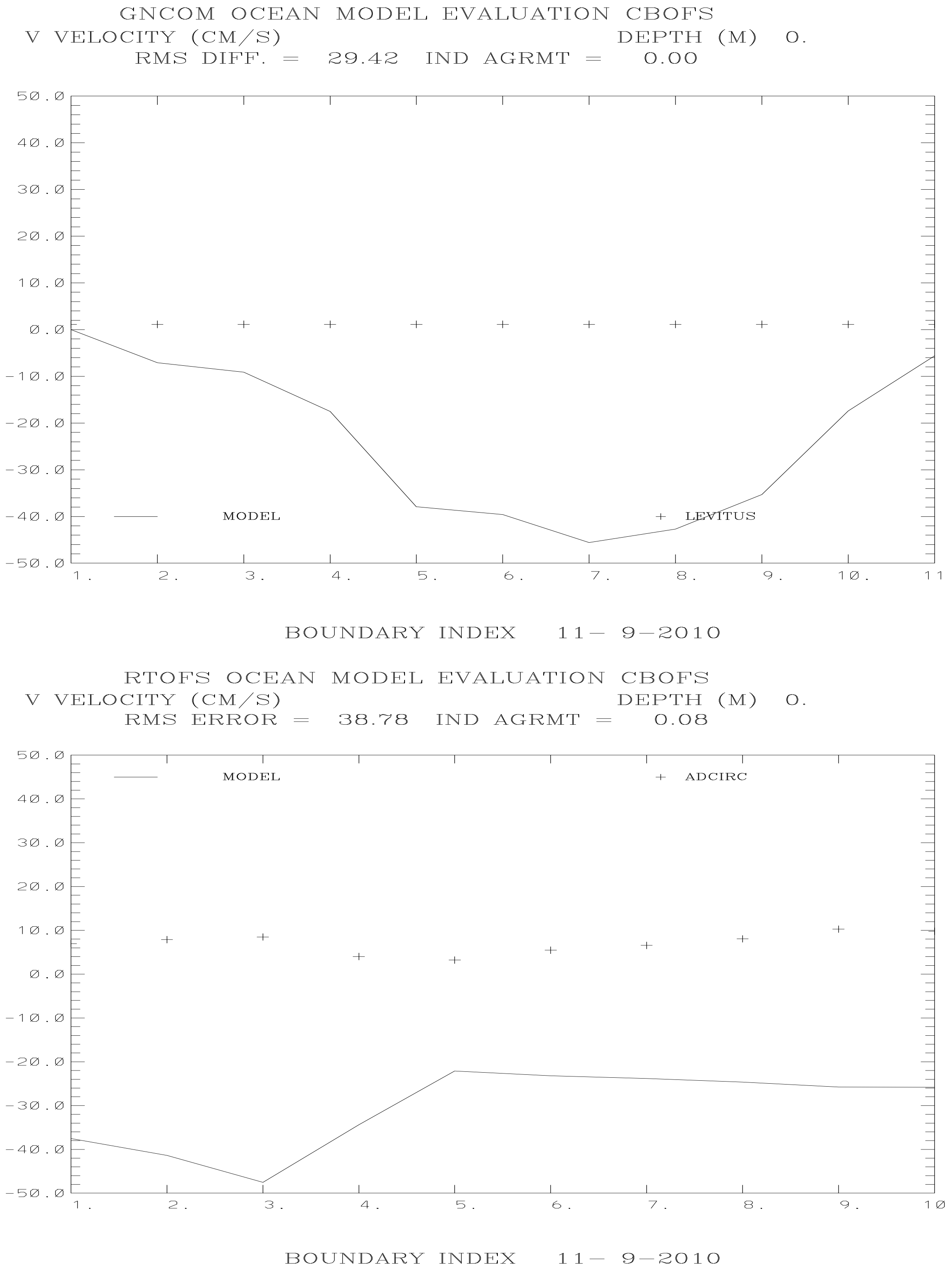
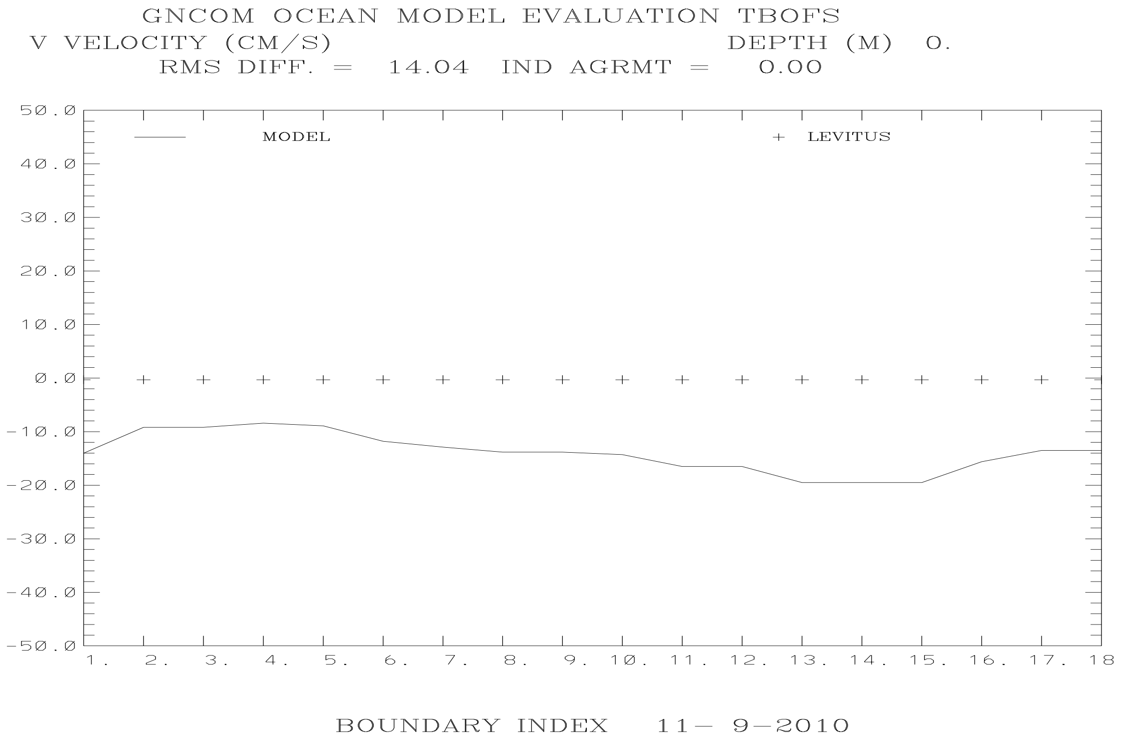


Figure 3.17. GNCOM and RTOFS surface V (North) velocity component at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the CBOFS open boundary.



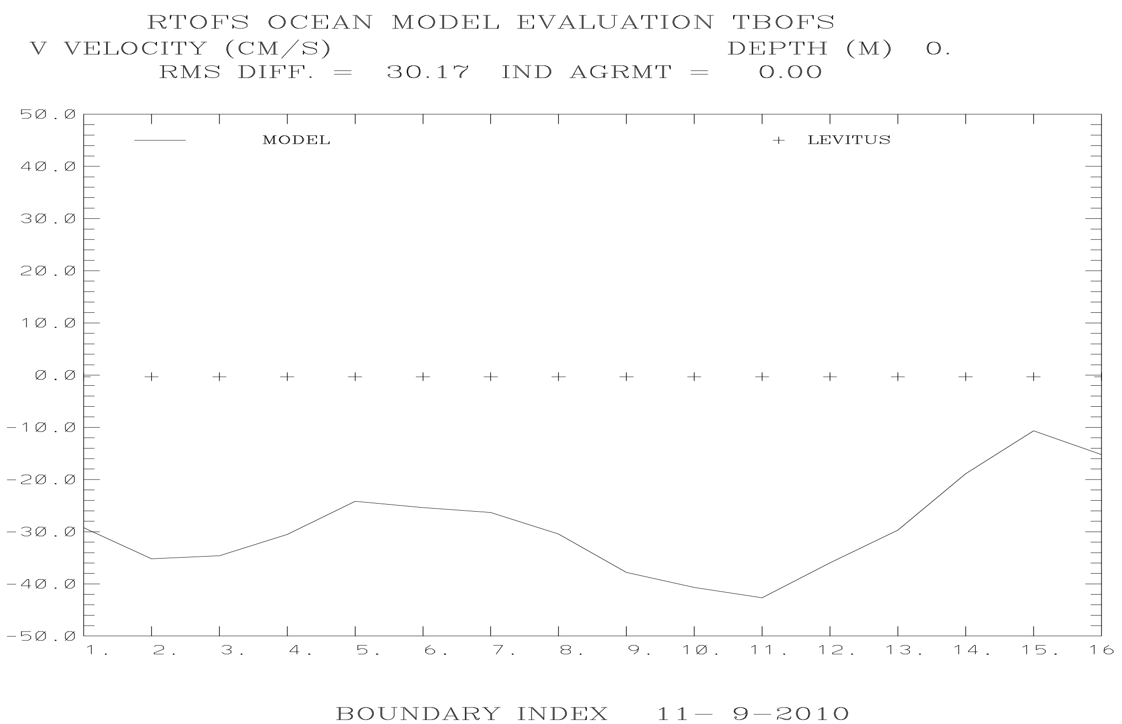


Figure 3.18. GNCOM and RTOFS surface V (North) velocity component at the start of the 11/09/2010 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the TBOFS open boundary.

4. FEBRUARY 2011 MONTHLY ANALYSIS

During February 2011, both the G-NCOM and RTOFS ocean model 00 UTC nowcast/forecast cycles were accessed to provide daily snapshots on February 22 and 23, 2011**.** Both cycles were analyzed with the results for both daily snapshots being very similar. As a result, we show here the results for February 23rd only**.**

In Table 4.1 for water temperature and in Table 4.2 for salinity, the two ocean model predictions are compared with the TESAC CTD profiles at two locations. It should be noted, that the purpose of these comparisons is to provide an initial spot check on the integrity of the ocean model vertical density structure. Within the analysis only every 10^{th} CTD profile is considered. In Figures 4.1 and 4.2, the salinity and water temperature profile comparisons at Station 41033 off the South Carolina coast are shown, respectively. Note the stratification index shown in the figures corresponds to Stratification Index One. In general, both ocean model profiles are vertically well-mixed, while considerable stratification is noted in both the observed salinity and water temperature profiles.

In Table 4.3, the ocean model salinity responses along the three NOS OFS boundaries are presented. The analysis considers every 10^{th} ocean model boundary point. Note for DBOFS, CBOFS, and TBOFS the number of boundary points is 128, 106, and 176, respectively. The responses are compared relative to the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 4.3 (DBOFS), Figure 4.4 (CBOFS), and in Figure 4.5 (TBOFS), the surface salinity ocean model responses corresponded closely to climatology along the TBOFS open boundary. The RTOFS forecast tended to exceed climatology by 2 to 3 PSU along both the DBOFS and CBOFS open boundaries, unlike the G-NCOM surface salinity responses, which are very near climatology. Near bottom salinity comparisons are not shown, but are very similar except along the DBOFS and CBOFS open boundaries, with RTOFS again above climatology by 2 PSU and G-NCOM very near climatology.

In Table 4.4, the ocean model water temperature responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10^{th} ocean model boundary point. The responses are compared relative the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 4.6 (DBOFS), Figure 4.7 (CBOFS), and in Figure 4.8 (TBOFS), the surface water temperature ocean model responses corresponded closely to climatology with one exception. The RTOFS forecast tended to exceed climatology by 4 to 5 ^{o}C along the DBOFS and CBOFS open boundary, unlike the G-NCOM surface water temperature response, which was closer to climatology. Near bottom water temperature comparisons are not shown, but are very similar except along the DBOFS open boundary, with RTOFS differing from climatology by 4 ^{o}C along some sections of the boundary and G-NCOM somewhat closer to climatology throughout.

In Table 4.5, the ocean model U (East) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10^{th} ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity may be different due to the different model depths and the difference in correspondence of the ocean model grid points to the OFS boundary grid points. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in Figure 4.9 (DBOFS), Figure 4.10 (CBOFS), and in Figure 4.11 (TBOFS), the surface U (East) velocity component ocean model responses are quite different along the DBOFS and CBOFS open boundaries. Note in these figures, the G-NCOM comparison to WOA 2001 climatology is labeled Levitus and the RTOFS forecast comparison is to the ADCIRC vertically integrated velocity component.

In Table 4.6, the ocean model V (North) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10^{th} ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. Note the depths shown for the ocean models, may be slightly different, as the ocean model forecasts are given on ocean model depth levels. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity may be different due to the different model depths and the difference in correspondence of the ocean model grid points to the OFS boundary grid points. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in Figure 4.12 (DBOFS) , Figure 4.13 (CBOFS), and in Figure 4.14 (TBOFS), the surface V (North) velocity component ocean model responses are quite different along all three OFS open boundaries. Note in these figures, the G-NCOM comparison to WOA 2001 climatology is labeled Levitus and the RTOFS forecast comparison is to the ADCIRC vertically integrated velocity component.

Table 4.1 Water Temperature (^{o}C) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data February 2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC-ATL= South Carolina Atlantic.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033 SC-ATL	2/23:0	12 20	1.85 1.74	34.01 35.11	30.14 32.70	34.34 35.10	34.44 35.88	3.97 3.17	0.12 0.09
41029 SC-ATL	2/23:0	35 -	0.22 -	36.06 -	35.42 -	36.19 -	36.17 -	0.63 -	0.02 -

Table 4.2. Salinity (PSU) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy ATL= South Carolina Atlantic.Data February 2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Note SC - ATL= South Carolina Atlantic.

Station Location	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41033 SC-ATL	2/23:0	12 20	4.13 7.11	14.19 4.64	11.16 8.68	14.06 4.76	11.97 16.21	0.68 7.41	0.06 0.60
41029 SC-ATL	2/23:0	10 -	3.70 -	14.33 -	11.52 -	14.33 -	10.69 -	0.83 -	0.07 -

Table 4.3. Salinity Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 2/23/2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2. Comparisons are made at every 10th grid point of each OFS.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.68 1.84	0.10 0.43	32.56 34.81	33.14 33.13
DBOFS	30 30	0.75 1.64	0.09 0.36	32.72 34.81	33.36 33.35
DBOFS	81 81	0.66 1.25	0.06 0.25	33.44 34.81	33.80 33.83
CBOFS	0 0	0.35 1.60	0.12 0.77	32.30 34.04	32.21 32.59
CBOFS	15 17	0.42 1.21	0.13 0.63	32.31 34.04	32.65 33.04
CBOFS	36 39	0.93 0.85	0.57 0.56	32.76 34.14	33.28 33.54
TBOFS	0 0	0.64 0.30	0.66 0.50	35.25 35.50	35.86 35.77
TBOFS	10 10	0.68 0.47	0.54 0.47	35.30 35.47	35.96 35.92
TBOFS	20 22	0.71 0.70	0.53 0.63	35.47 35.47	36.14 36.15

Table 4.4. Water Temperature Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 2/23/2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th grid point of each OFS.

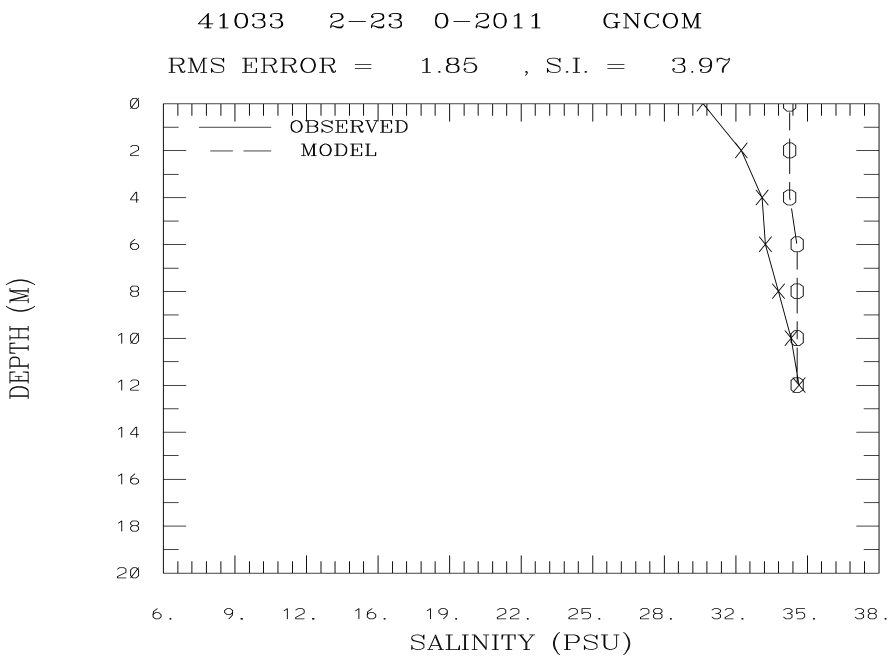
NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.78 3.23	0.04 0.26	7.39 8.77	7.02 6.85
DBOFS	30 30	0.96 3.01	0.04 0.22	7.74 8.80	7.13 7.00
DBOFS	81 81	1.61 2.62	0.10 0.17	8.66 8.74	7.46 7.54
CBOFS	0 0	0.74 0.89	0.11 0.11	7.85 7.05	7.36 7.68
CBOFS	15 17	0.78 0.87	0.12 0.10	7.90 7.14	7.37 7.76
CBOFS	36 39	1.63 1.41	0.47 0.35	8.50 7.34	7.57 8.01
TBOFS	0 0	0.49 0.28	0.26 0.26	18.23 18.33	18.70 18.42
TBOFS	10 10	1.27 0.21	0.68 0.25	17.31 18.16	18.52 18.19
TBOFS	20 22	1.31 0.37	0.59 0.28	17.09 18.01	18.35 18.01

Table 4.5. U (East) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 2/23/2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	36.68 46.10	0.91 0.95	41.03 46.12	1.00 1.00	-30.14 -3.84	4.12 4.12	10.25 10.25
DBOFS	30 30	32.43 46.63	0.91 0.96	36.05 46.18	0.99 1.00	-24.39 4.40	4.12 4.12	9.99 9.99
DBOFS	81 81	24.30 43.70	0.86 0.96	27.83 43.44	0.96 1.00	-17.63 7.36	4.12 4.12	9.37 9.33
CBOFS	0 0	35.00 57.87	0.87 0.92	31.61 53.92	1.00 1.00	-21.12 -45.01	6.62 7.27	8.61 8.61
CBOFS	15 17	30.73 46.26	0.83 0.89	27.42 42.20	1.00 1.00	-17.37 -33.54	6.62 7.27	8.48 8.47
CBOFS	36 39	25.10 41.00	0.77 0.88	21.75 36.57	0.99 0.99	-12.35 -27.98	6.62 7.27	8.17 8.14
TBOFS	0 0	18.46 7.28	0.88 0.70	18.14 7.45	1.00 1.00	-15.19 -3.35	2.39 2.19	2.00 2.00
TBOFS	10 10	16.26 10.34	0.87 0.79	15.88 10.25	0.99 0.98	-13.37 -6.25	2.39 2.19	1.92 1.91
TBOFS	20 22	10.73 8.91	0.83 0.79	10.02 8.37	0.99 0.98	-7.25 -5.32	2.39 2.19	1.76 1.74

Table 4.6. V (North) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 2/23/2011. G-NCOM predictions are in row 1 with RTOFS predictions in row 2 at every 10th OFS grid point.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	18.65 16.02	0.76 0.57	17.71 18.07	1.00 1.00	-8.82 0.94	8.10 8.10	7.98 7.98
DBOFS	30 30	15.74 16.10	0.70 0.56	15.29 18.38	0.99 0.99	-5.55 2.35	8.10 8.10	8.10 8.10
DBOFS	81 81	18.66 16.43	0.71 0.57	18.33 18.21	0.97 0.93	-9.23 2.01	8.10 8.10	7.96 7.95
CBOFS	0 0	38.76 16.78	0.91 0.78	32.12 10.05	1.00 1.00	-26.42 -5.22	9.96 10.63	3.36 3.36
CBOFS	15 17	31.24 15.86	0.89 0.76	24.72 9.47	1.00 1.00	-19.48 -4.32	9.96 10.63	3.51 3.53
CBOFS	36 39	24.81 17.31	0.86 0.79	18.15 10.81	1.00 0.99	-13.45 -5.86	9.96 10.63	3.54 3.55
TBOFS	0 0	6.75 11.80	0.66 0.78	3.98 7.55	1.00 1.00	-1.68 -4.74	3.00 3.17	-3.56 -3.56
TBOFS	10 10	8.12 10.64	0.66 0.77	2.22 7.42	0.94 0.98	-4.01 -2.98	3.00 3.17	-3.49 -3.48
TBOFS	20 22	9.77 9.20	0.69 0.75	3.71 6.00	0.93 0.95	-5.83 -2.07	3.00 3.17	-3.30 -3.27



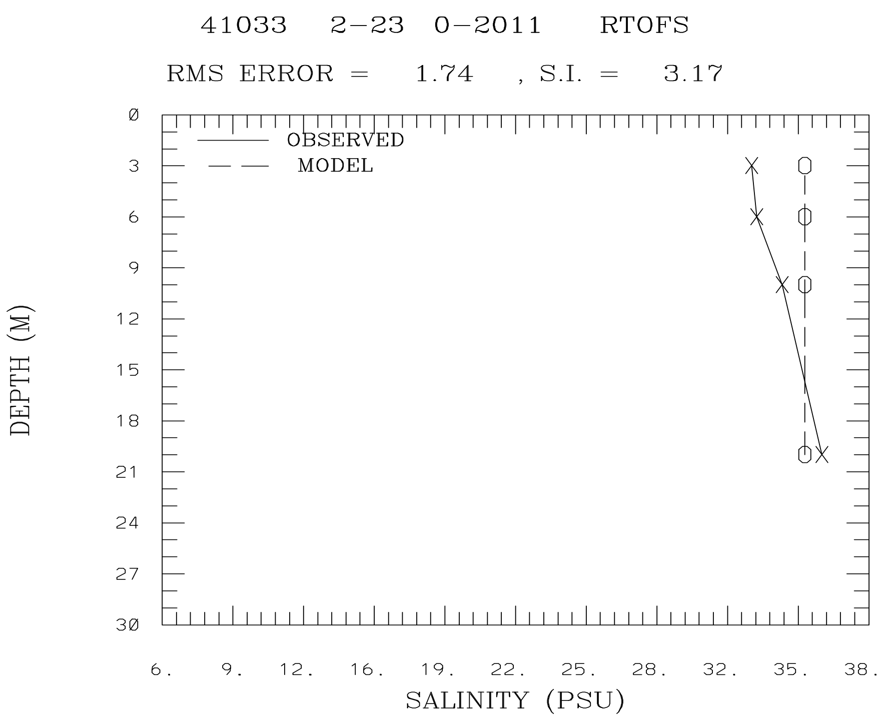
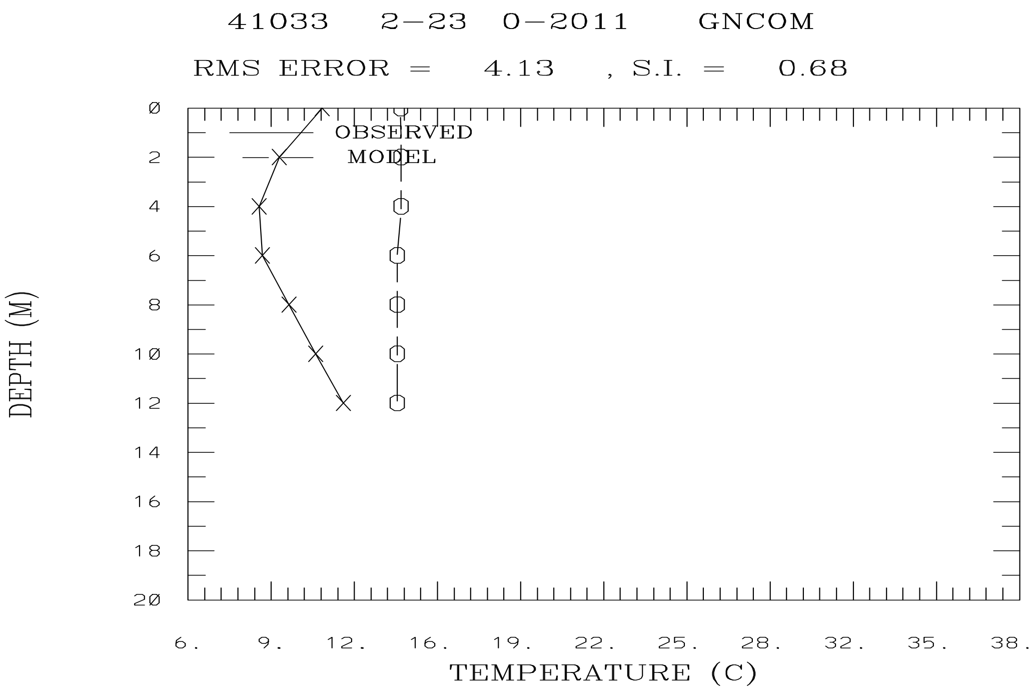


Figure 4.1. G-NCOM and RTOFS salinity forecast profile at Station 41033 data versus model comparisons on February 23, 2011 at hour 00 UTC.



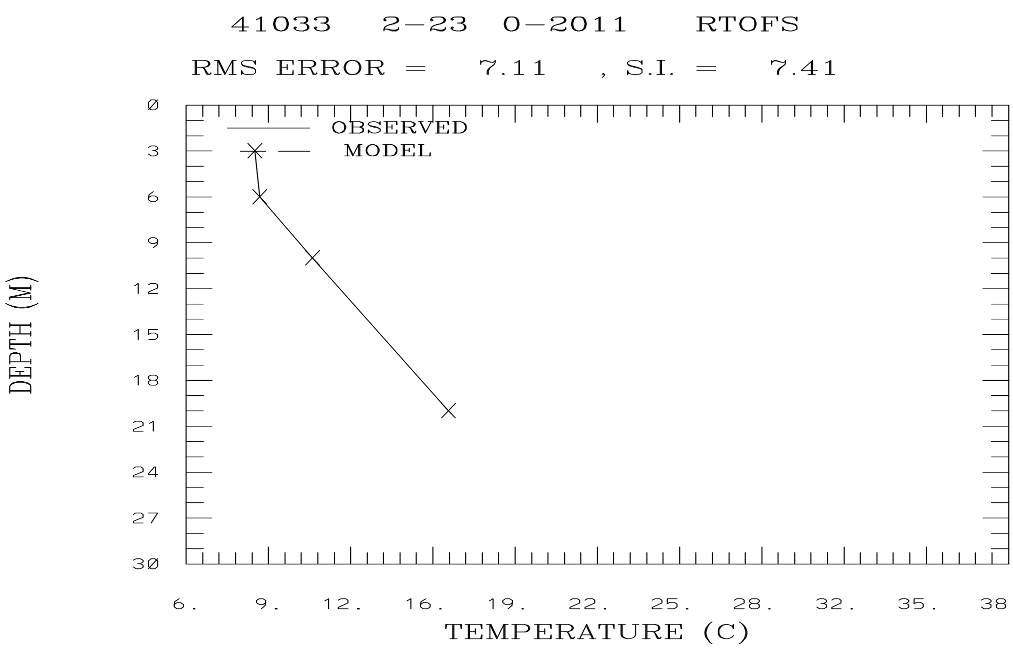
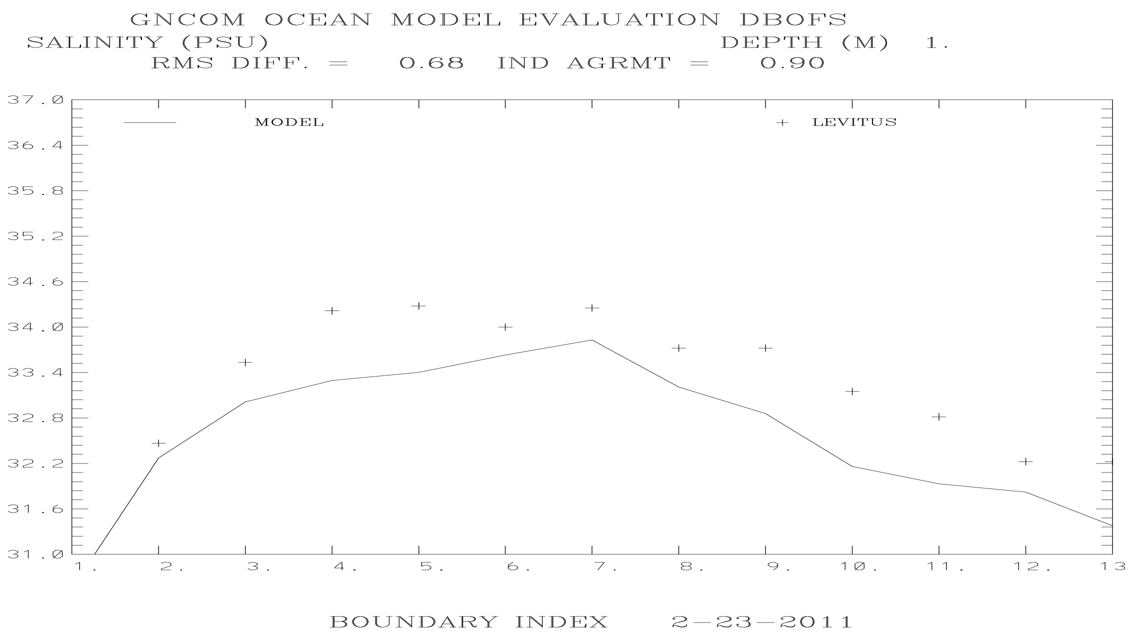


Figure 4.2. G-NCOM and RTOFS water temperature forecast profile at Station 41033 data versus model comparisons on February 23, 2011 at hour 00 UTC. Note the RTOFS forecast is below 6^{o}C.



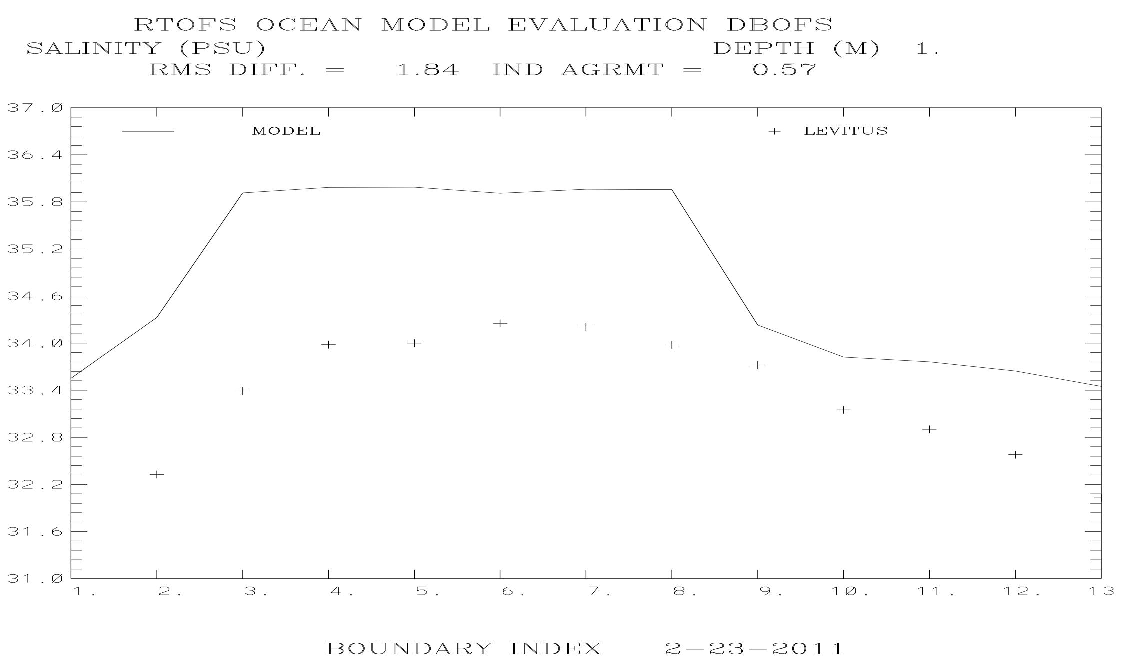
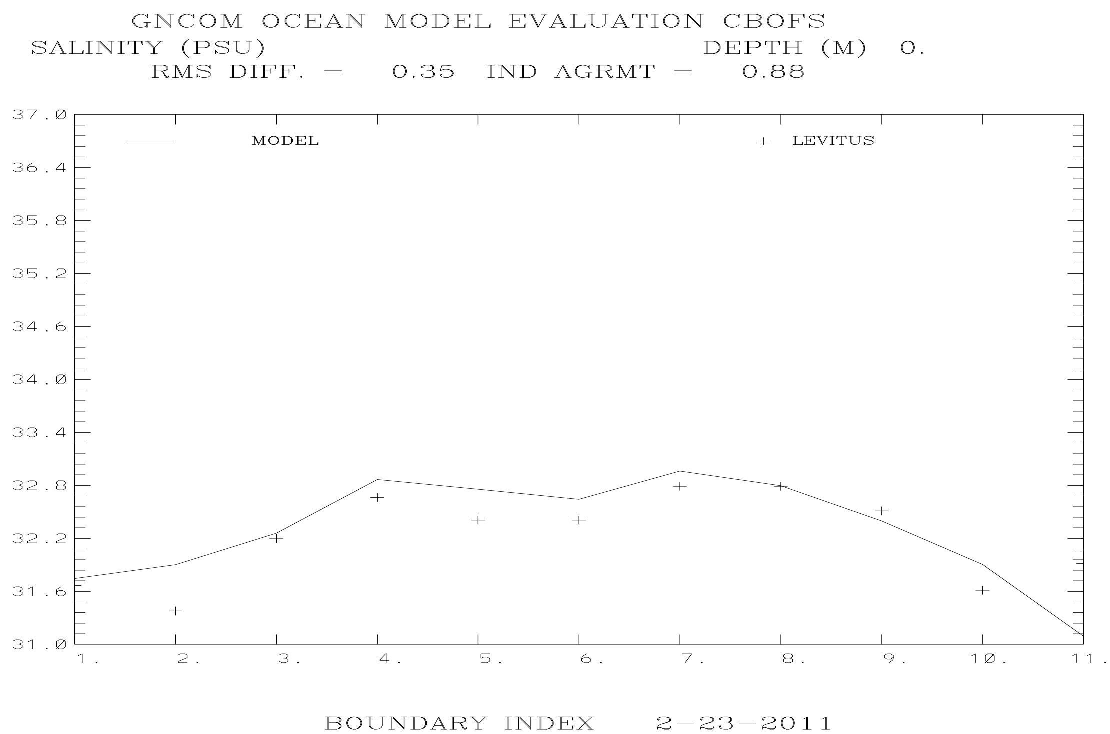


Figure 4.3. GNCOM and RTOFS surface salinity at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



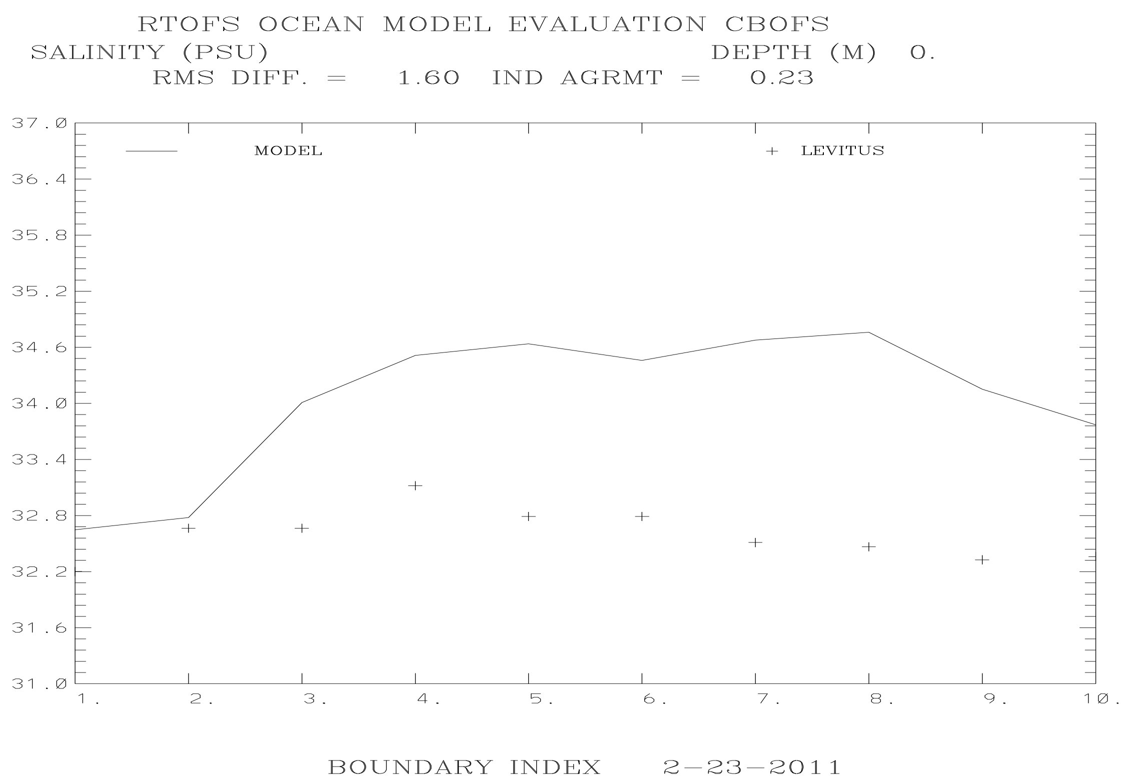
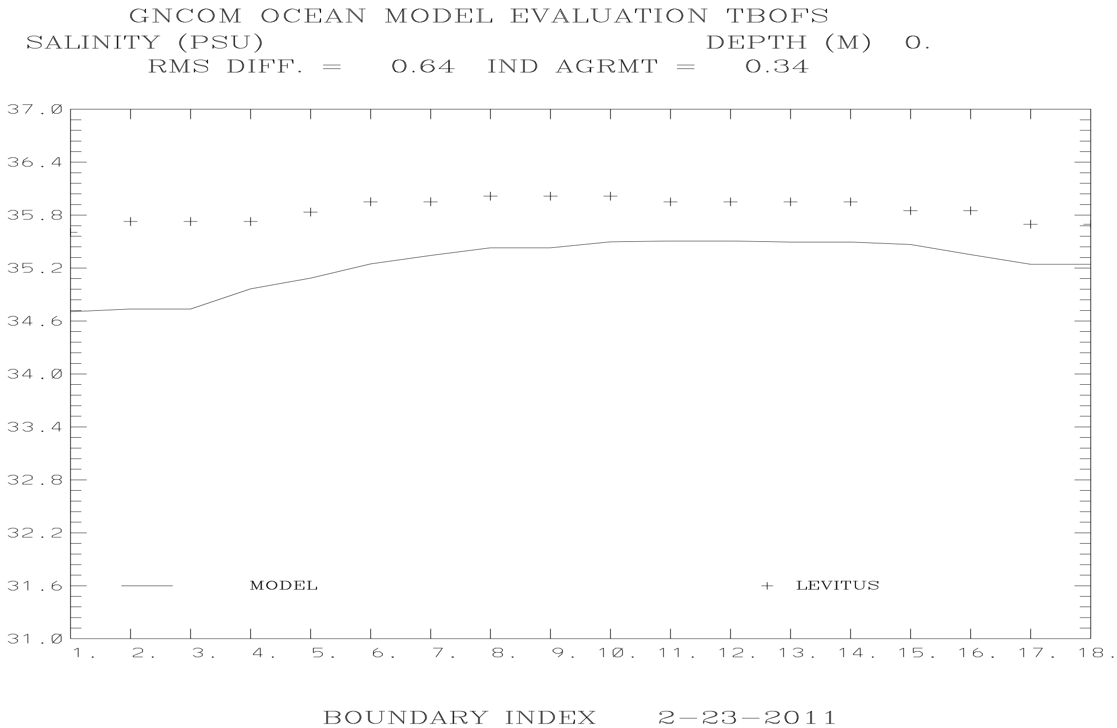


Figure 4.4. GNCOM and RTOFS surface salinity at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



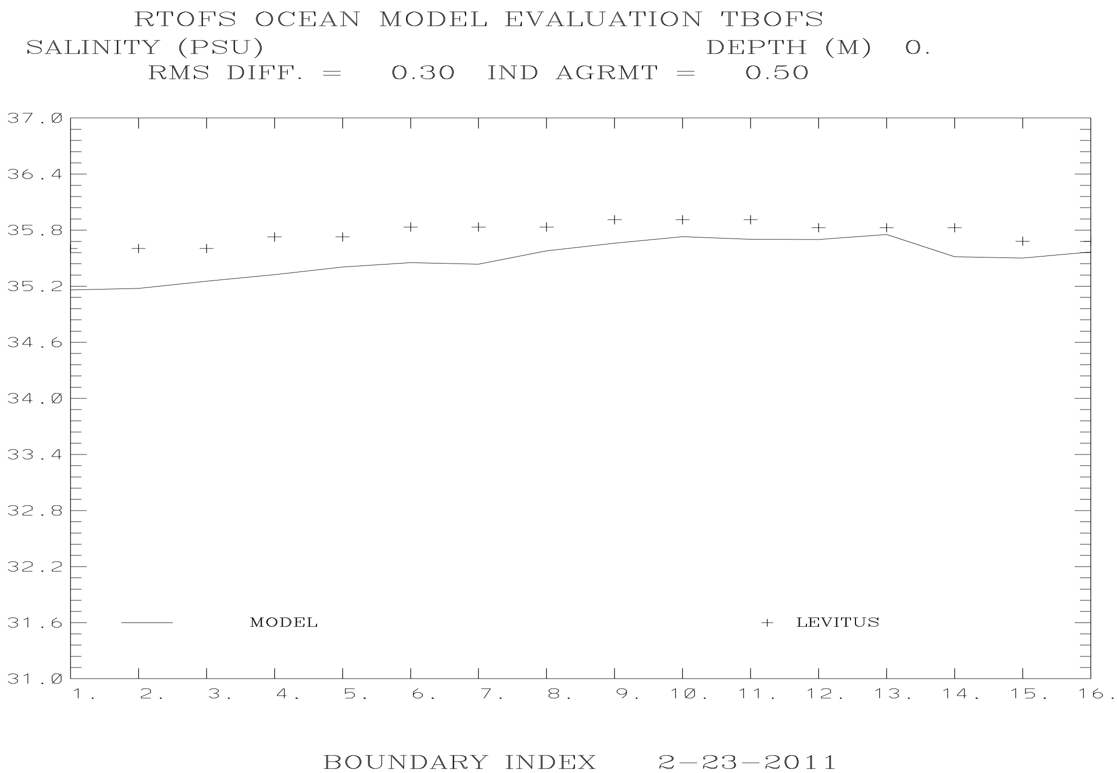
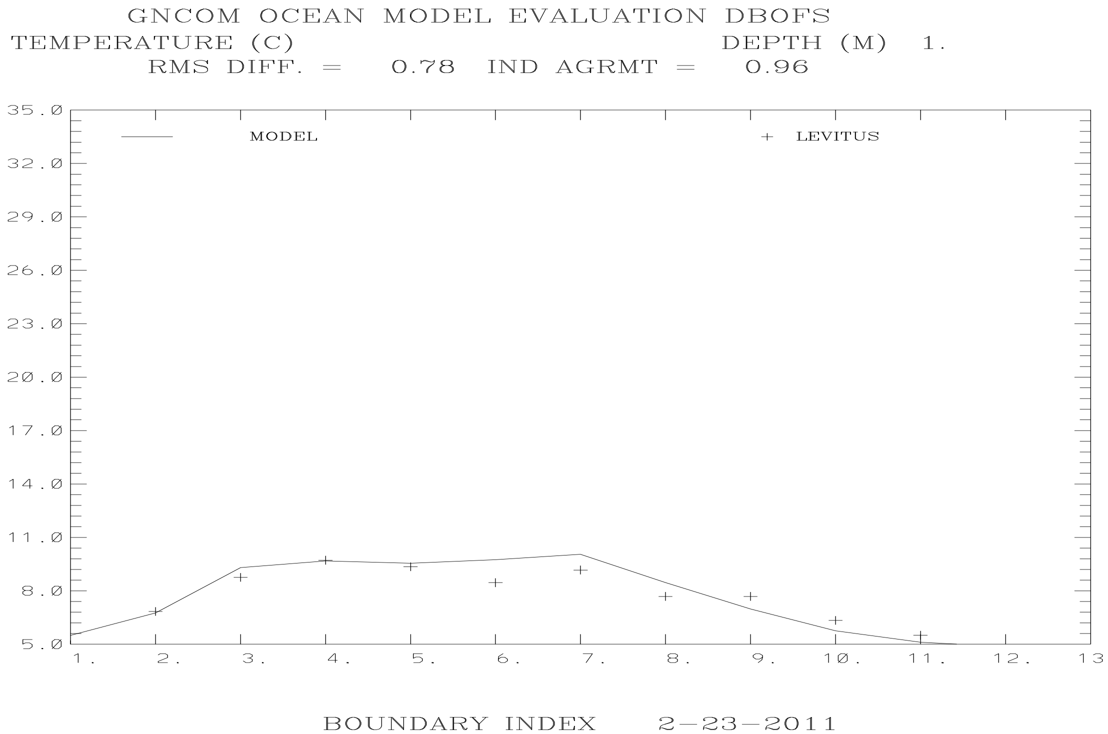


Figure 4.5. GNCOM and RTOFS surface salinity at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.



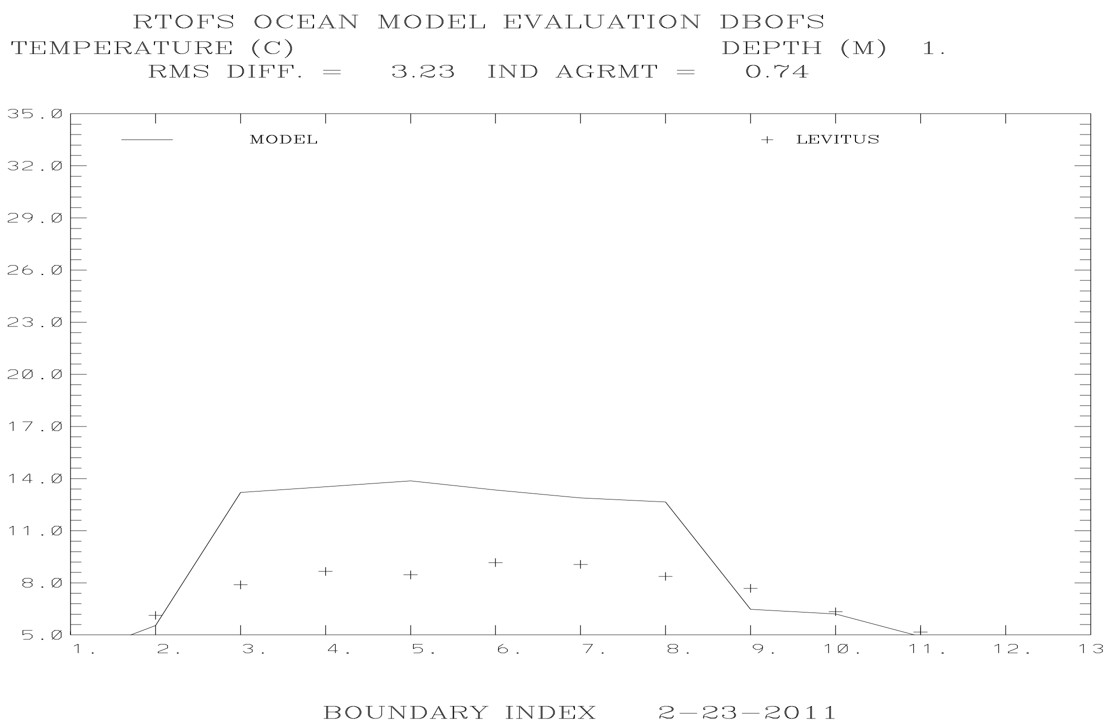
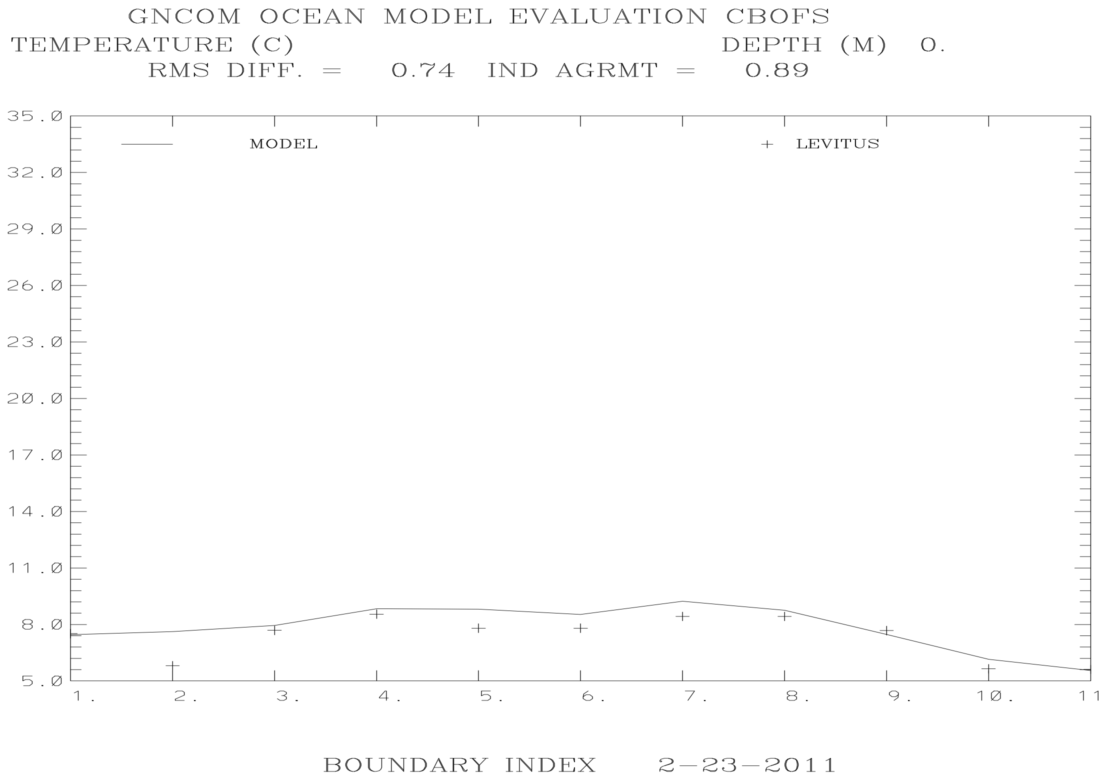


Figure 4.6. GNCOM and RTOFS surface water temperature at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



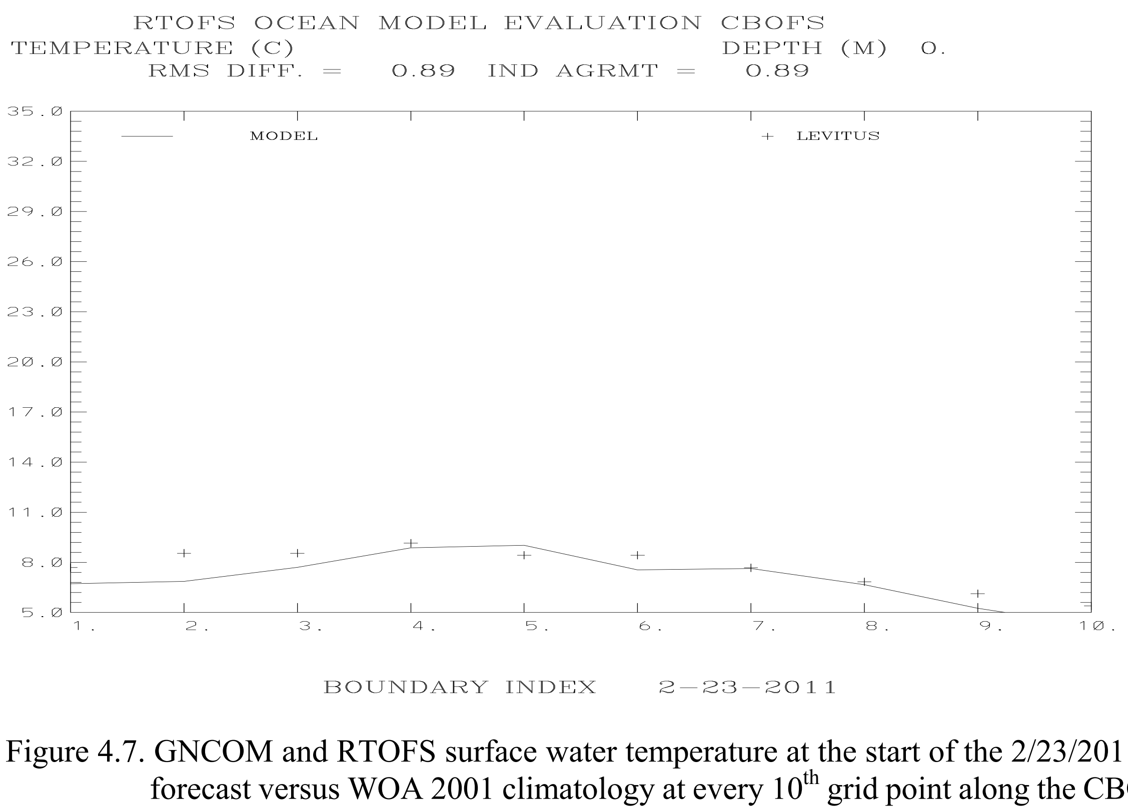
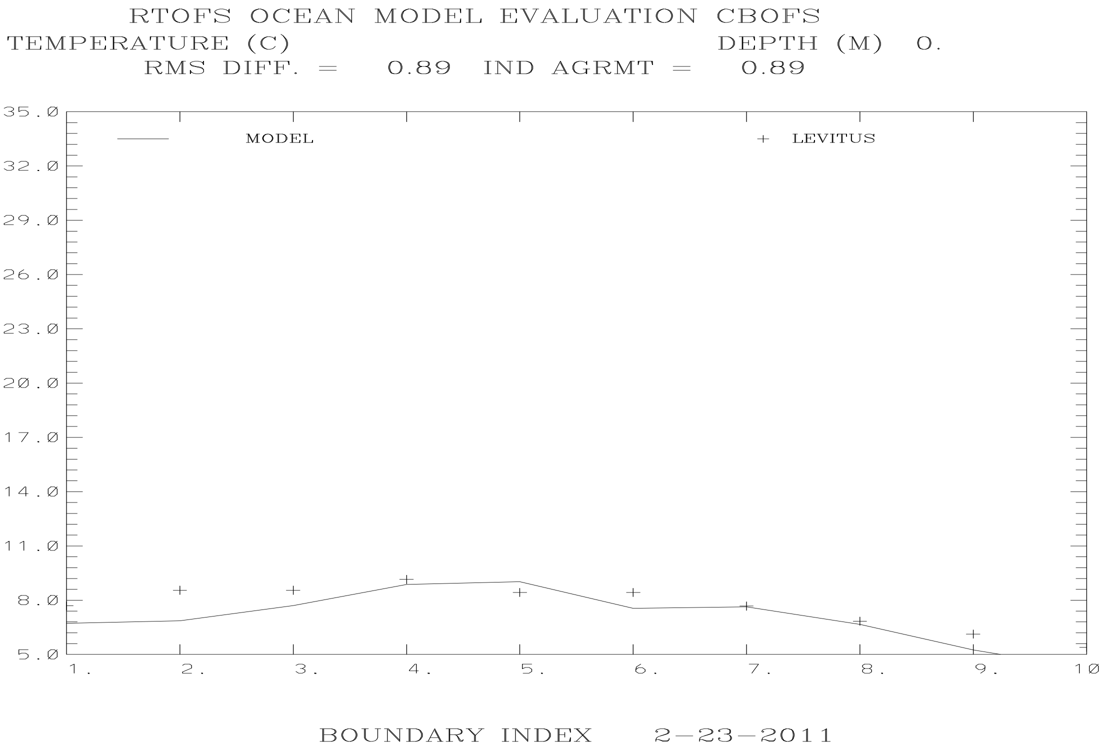


Figure 4.7. GNCOM and RTOFS surface water temperature at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



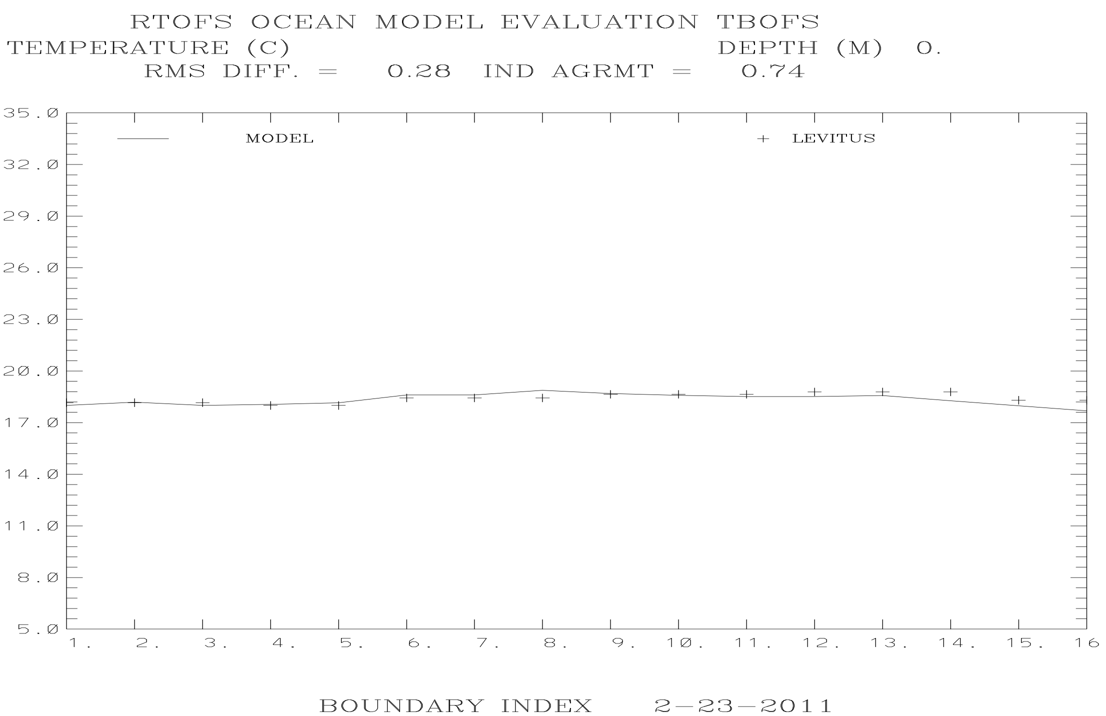
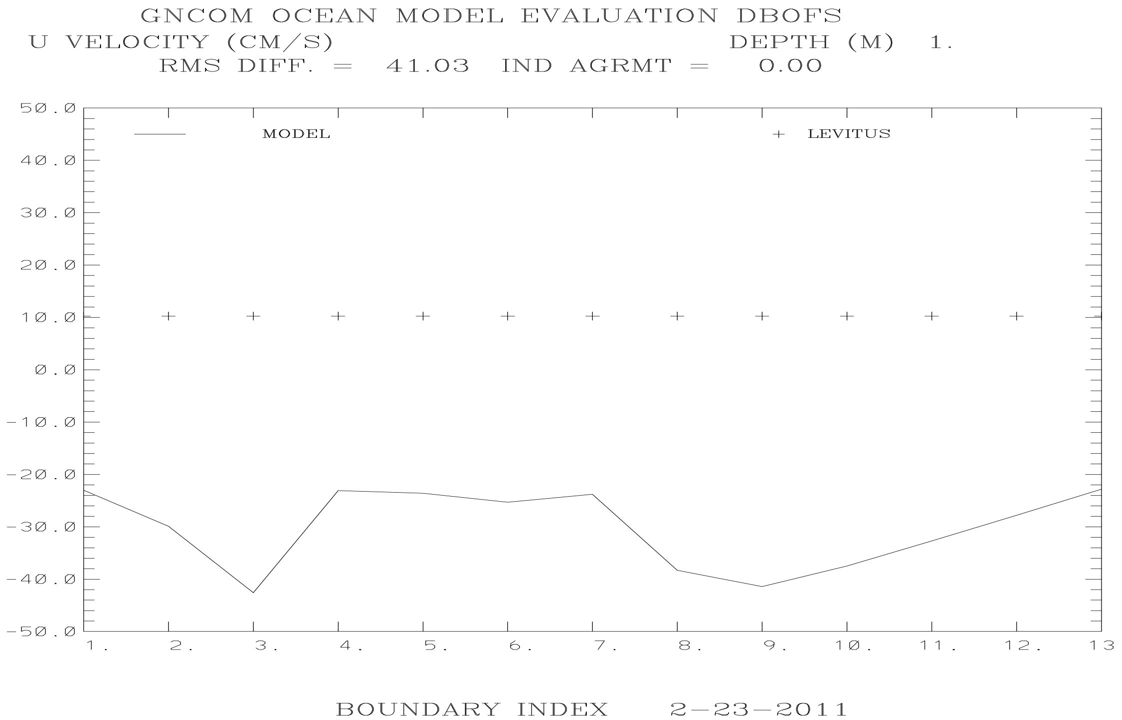


Figure 4.8. GNCOM and RTOFS surface water temperature at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology at every 10^{th} grid point along the TBOFS open boundary.



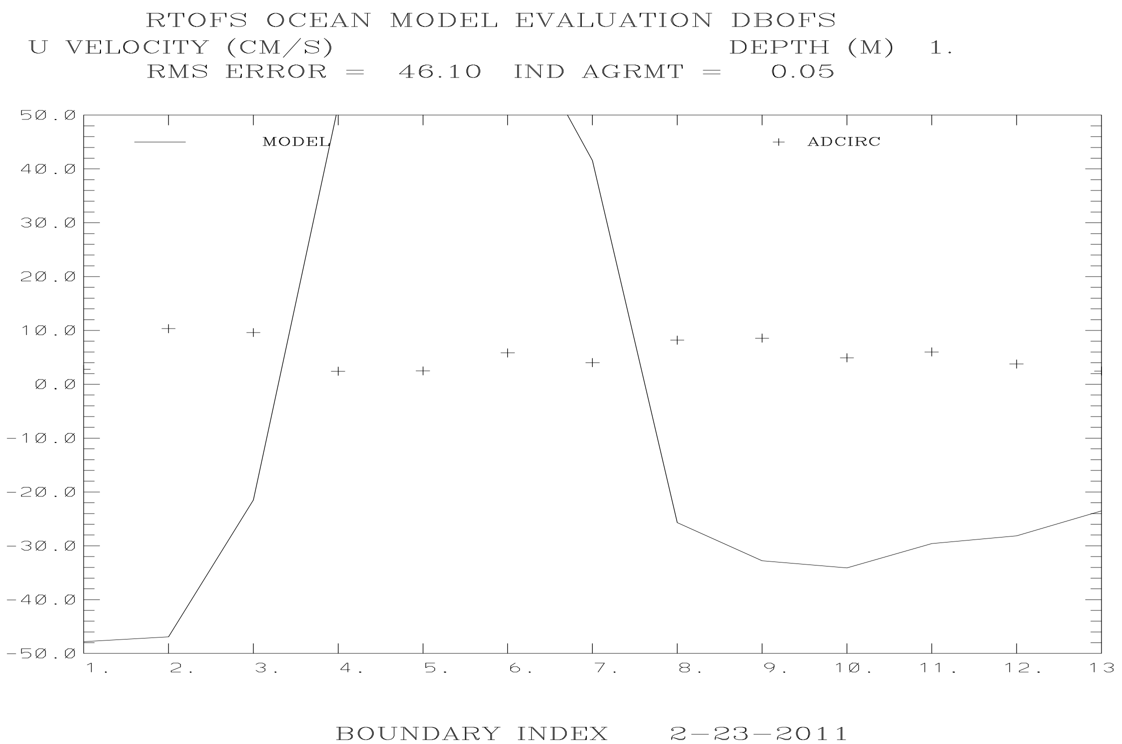
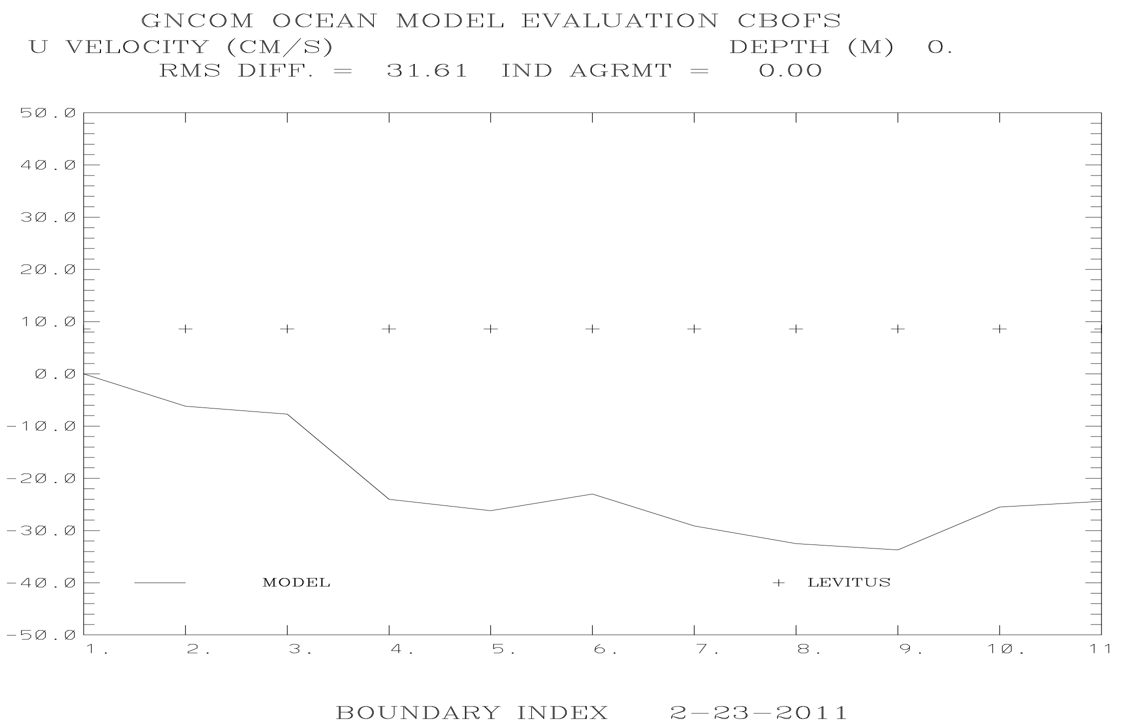


Figure 4.9. GNCOM and RTOFS surface U (East) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the DBOFS open boundary.



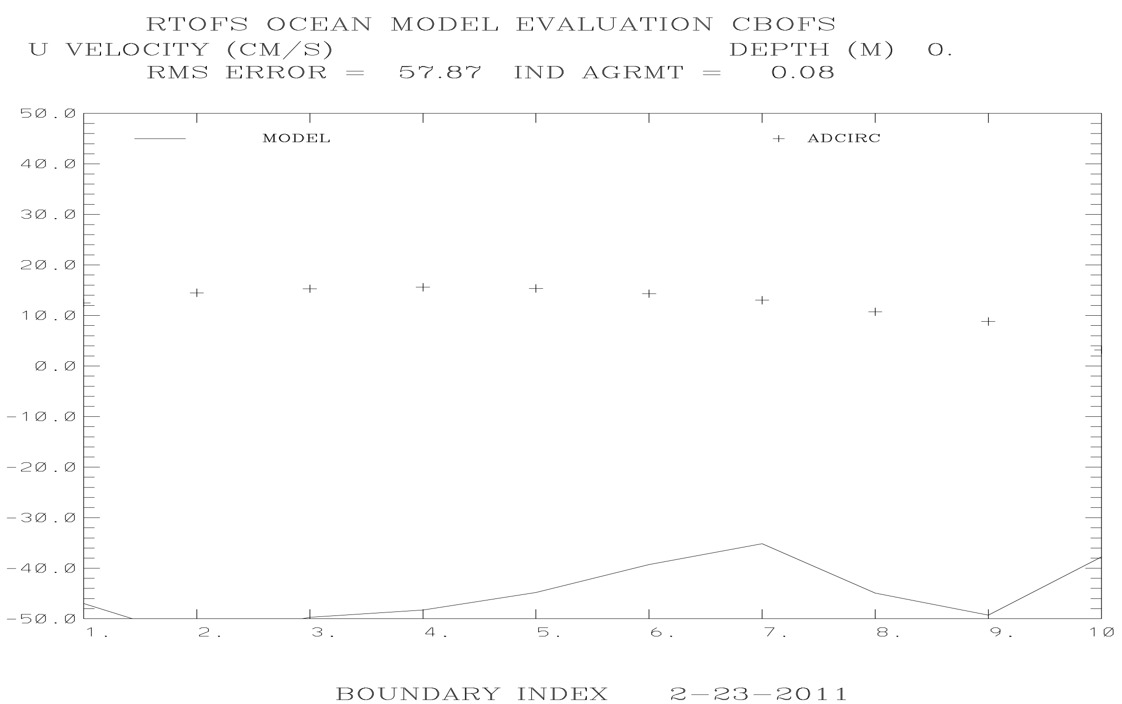
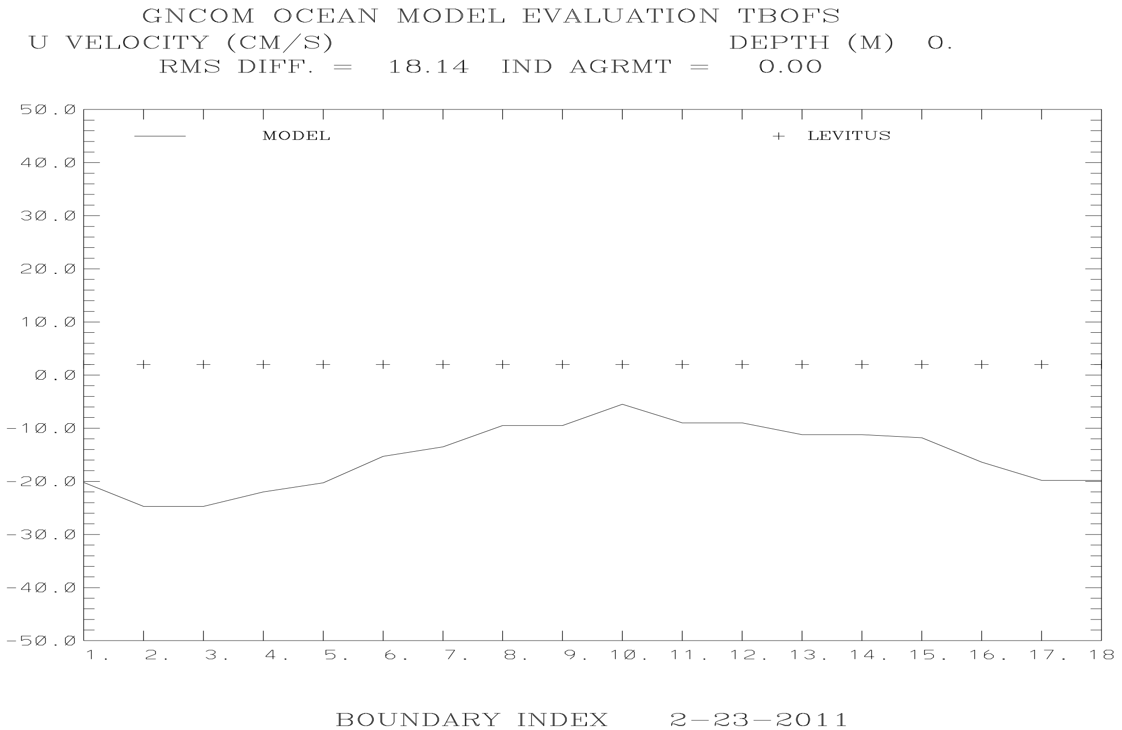


Figure 4.10. GNCOM and RTOFS surface U (East) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the CBOFS open boundary.



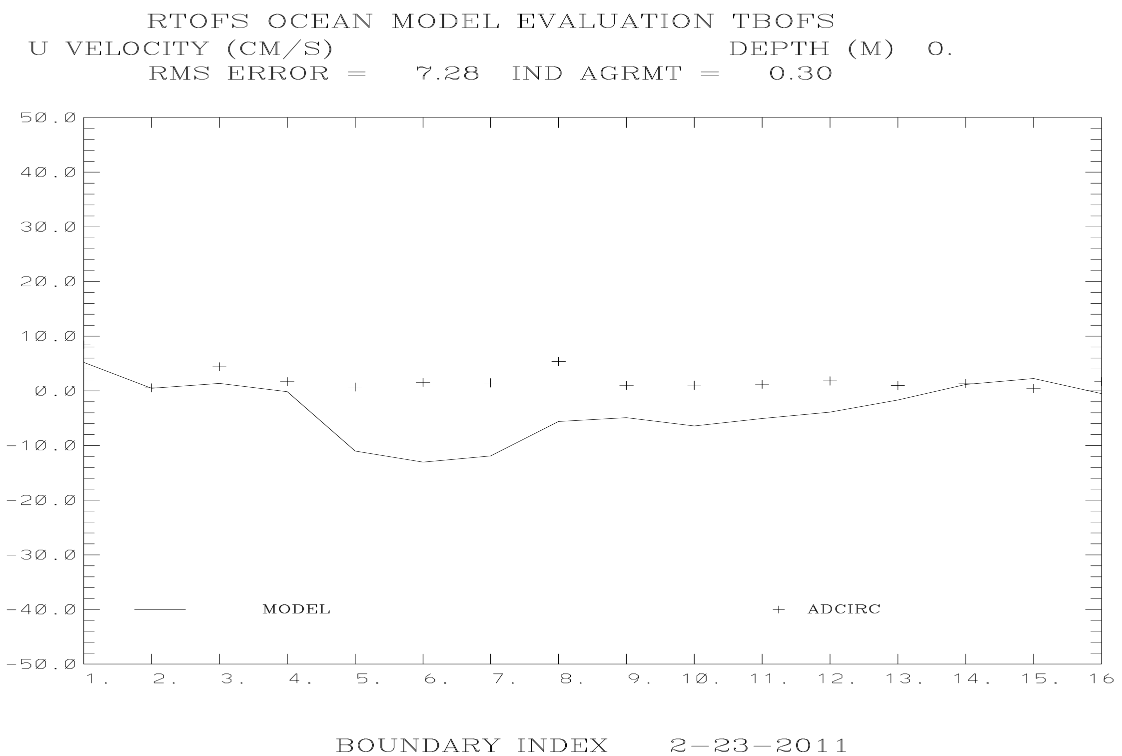
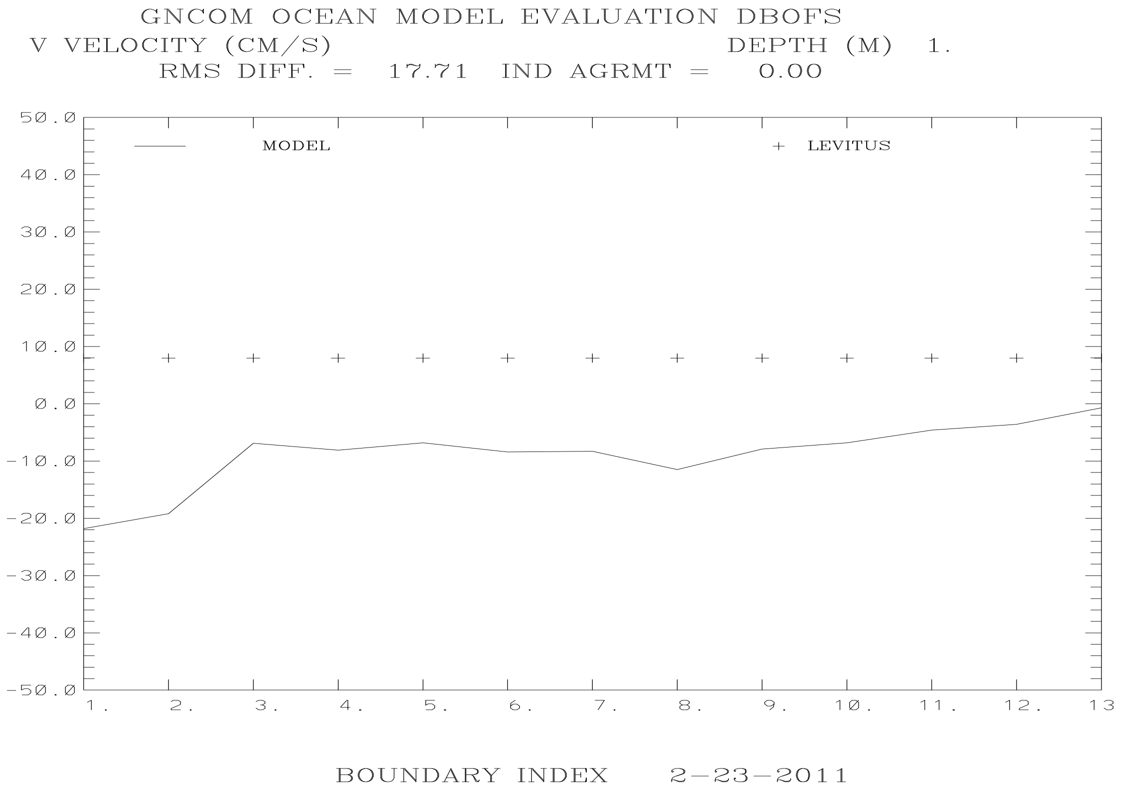


Figure 4.11. GNCOM and RTOFS surface U (East) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the TBOFS open boundary.



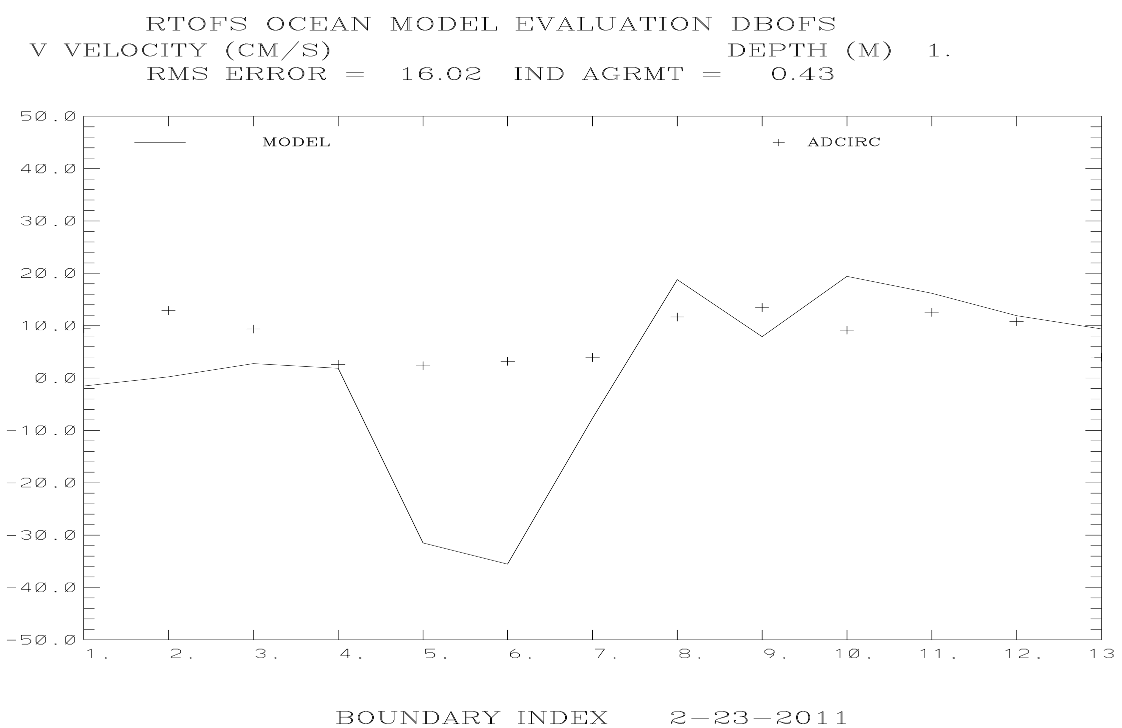


Figure 4.12. GNCOM and RTOFS surface V (North) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the DBOFS open boundary.

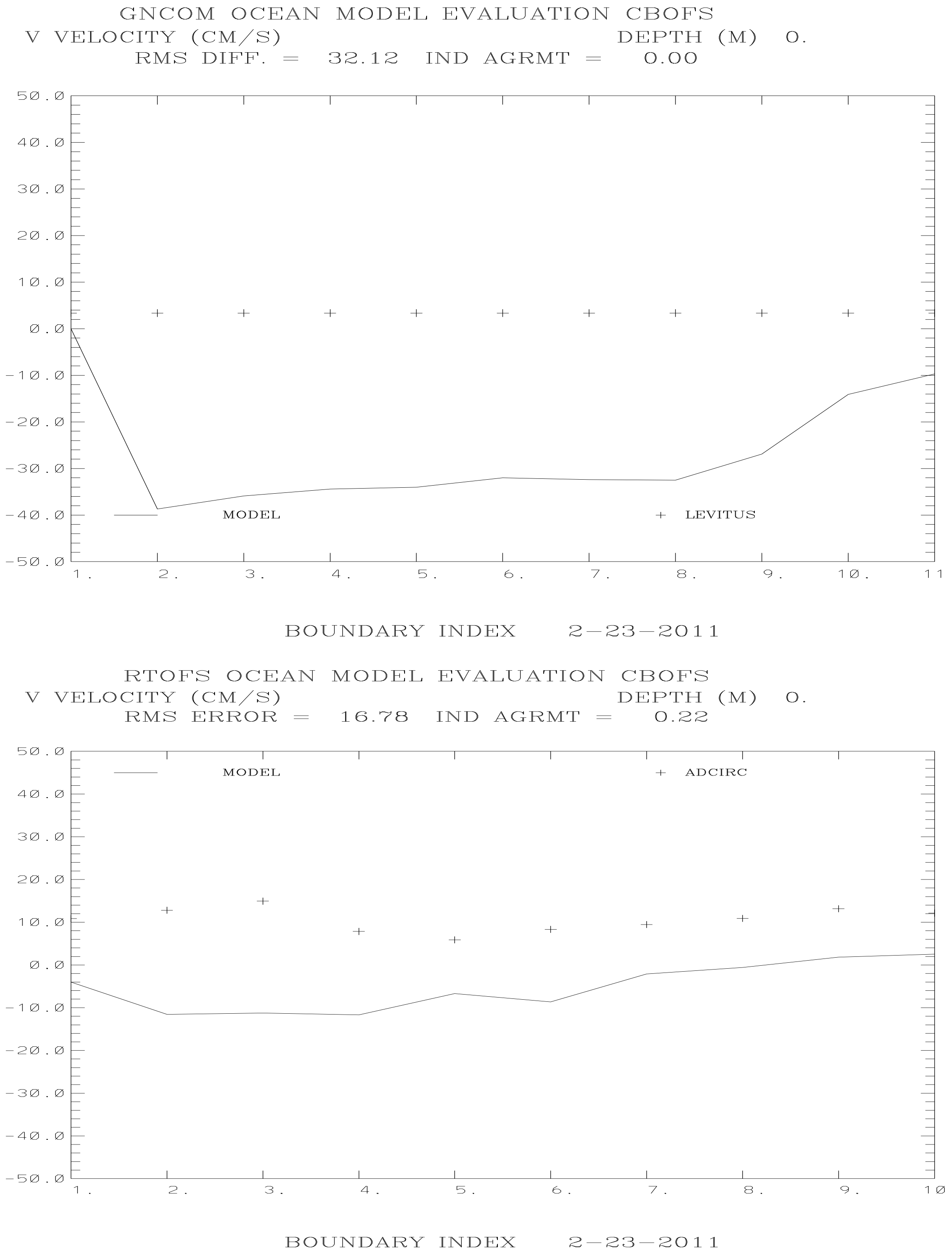
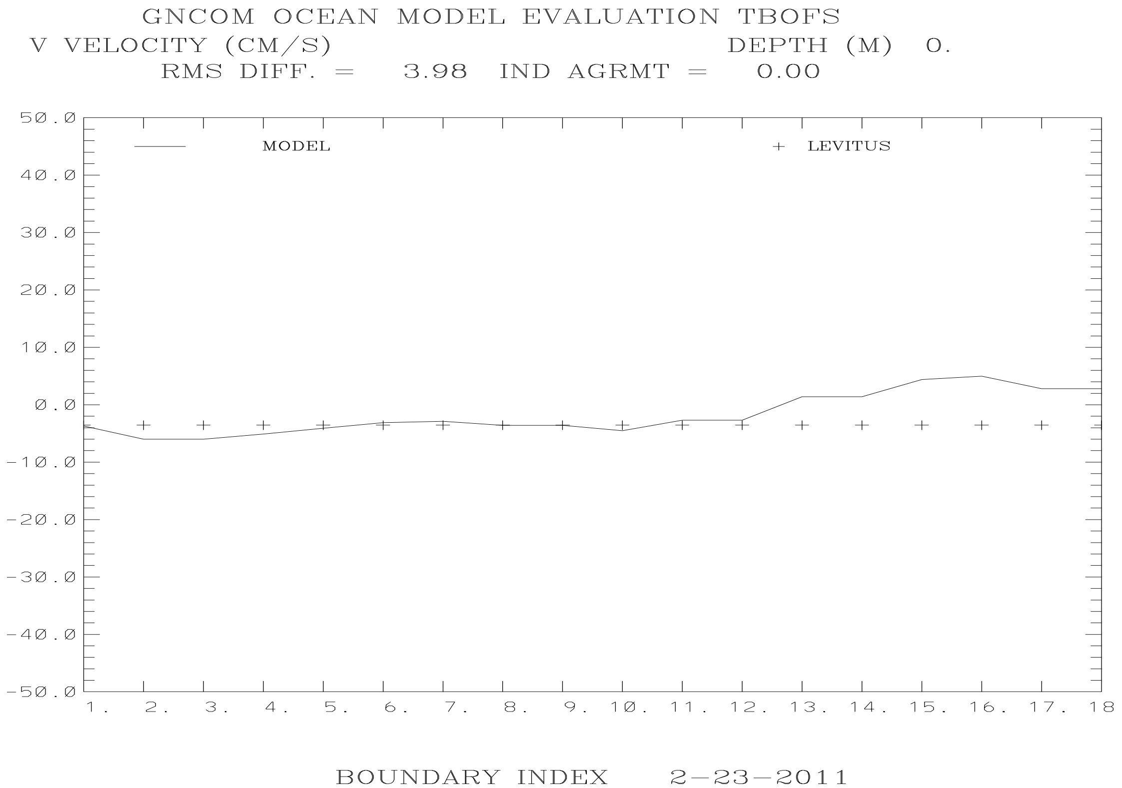


Figure 4.13. GNCOM and RTOFS surface V (North) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the CBOFS open boundary.



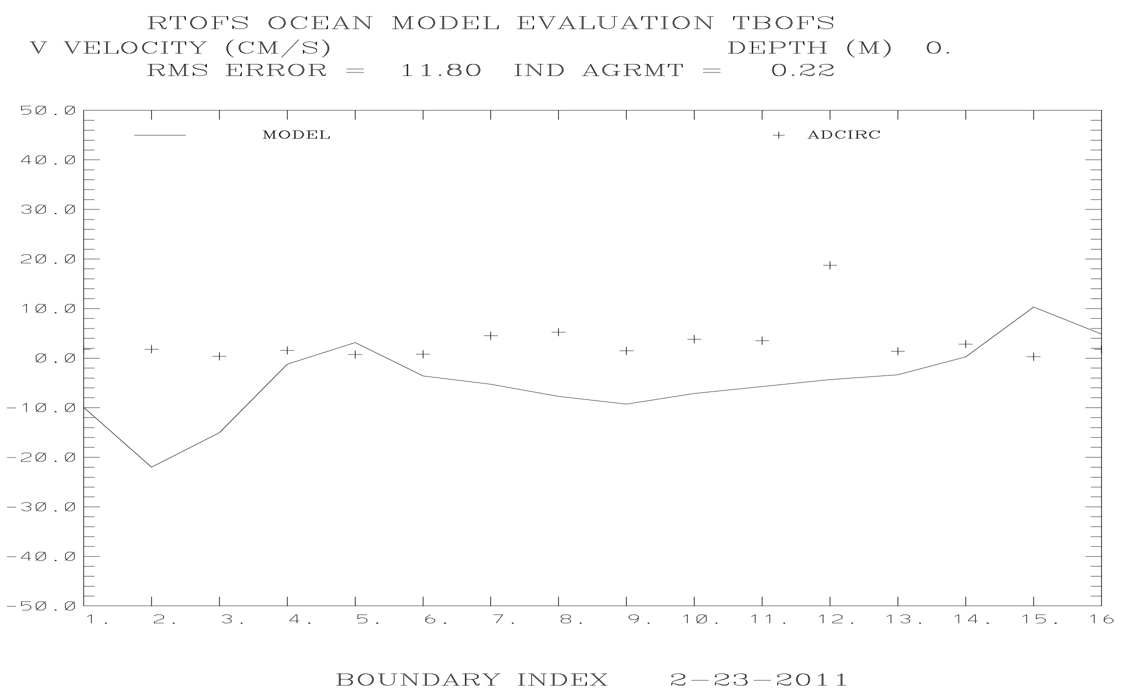


Figure 4.14. GNCOM and RTOFS surface V (North) velocity component at the start of the 2/23/2011 00 UTC forecast versus WOA 2001 climatology and ADCIRC at every 10th grid point along the TBOFS open boundary.

5. MAY 2011 MONTHLY ANALYSIS

During May 2011, only the G-NCOM ocean model 00 UTC nowcast/forecast cycles were accessed to provide daily snapshots on May 16 and 17, 2011**.** RTOFS forecasts were not available from the Ocean NOMADS server, due to a server failure and were not recreated from the netCDF files as all conversion software was lost. Both G-NCOM cycles were analyzed with the results for both daily snapshots being very similar. As a result, we show here the G-NCOM results for May 16th only**.**

In Table 5.1 for water temperature and in Table 5.2 for salinity, the G-NCOM predictions are compared with the TESAC CTD profiles at two locations. It should be noted, that the purpose of these comparisons is to provide an initial spot check on the integrity of the ocean model vertical density structure. Within the analysis only every 10th CTD profile is considered. In Figures 5.1 and 5.2, the salinity and water temperature profile comparisons are shown graphically. Note the stratification index shown corresponds to Stratification Index One. In general, the G-NCOM ocean model profiles are vertically well-mixed, while considerable stratification is noted in both the observed salinity and water temperature profiles. At Station 44062 in the mid-Chesapeake Bay, the G-NCOM salinity response was much saltier than the observation.

In Table 5.3, the ocean model salinity responses along the three NOS OFS boundaries are presented. The analysis considers every 10th ocean model boundary point. Note for DBOFS, CBOFS, and TBOFS the number of boundary points is 128, 106, and 176, respectively. The G-NCOM response is compared relative to the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 5.3 (DBOFS), Figure 5.4 (CBOFS), and in Figure 5.5 (TBOFS), the G-NCOM surface and near bottom salinity ocean model responses corresponded closely to climatology.

In Table 5.4, the G-NCOM water temperature responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 5.6 (DBOFS), Figure 5.7 (CBOFS), and in Figure 5.8 (TBOFS), the surface responses corresponded more closely to climatology than the near bottom water temperature response.

In Table 5.5, the G-NCOM U (East) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity. The G-NCOM, ADCIRC mean and WOA 2001 means are given. As may be seen in the top half of Figure 5.9 (DBOFS) , Figure 5.10 (CBOFS), and in Figure 5.11 (TBOFS), the G-NCOM surface U (East) velocity component ocean model responses are quite different along the DBOFS and CBOFS open boundaries relative to WOA 2001 climatology, which is labeled Levitus.

In Table 5.6, the ocean model V (North) velocity component responses along the three OFS boundaries are presented. Again the analysis considers every 10^{th} ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in lower half of Figure 5.9 (DBOFS), Figure 5.10 (CBOFS), and in Figure 5.11 (TBOFS), the G-NCOM surface V (North) velocity component ocean model responses are quite different along all the DBOFS and CBOFS OFS open boundaries relative to WOA 2001 climatology, which is labeled Levitus.

Table 5.1. Water Temperature (^oC) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data May 2011. G-NCOM predictions are given in row 1 and no RTOFS predictions are available.
Note SC/NC-ATL=South/North Carolina Atlantic and MD-CB=Maryland Chesapeake Bay.

Station	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41024 SC/NC-ATL	5/16:0	12 -	2.05 -	21.55 -	22.62 -	21.53 -	18.90 -	3.70 -	0.18 -
44062 MD-CB	5/16:0	6 -	1.33 -	15.84 -	18.05 -	15.90 -	15.91 -	2.08 -	0.12 -

Table 5.2. Salinity (PSU) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data May 2011. G-NCOM predictions are given in row 1 and no RTOFS predictions are available.
Note SC/NC-ATL=South/North Carolina Atlantic and MD-CB=Maryland Chesapeake Bay.

Station	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41024 SC/NC-ATL	5/16:0	12 -	0.46 -	34.40 -	33.83 -	34.45 -	34.97 -	1.09 -	0.03 -
44062 MD-CB	0	6 -	18.27 -	27.73 -	5.20 -	27.27 -	13.85 -	8.19 -	0.86 -

Table 5.3. Salinity Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 5/16/2011. G-NCOM predictions are in row 1 at every 10^{th} OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	1.53 -	0.61 -	31.73 -	32.01 -
DBOFS	30 30	1.43 -	0.26 -	32.42 -	32.65 -
DBOFS	81 81	1.27 -	0.17 -	33.49 -	33.36 -
CBOFS	0 0	1.36 -	0.59 -	31.83 -	30.70 -
CBOFS	15 17	1.22 -	0.53 -	32.25 -	31.45 -
CBOFS	36 39	0.91 -	0.80 -	32.79 -	32.57 -
TBOFS	0 0	0.07 -	0.04 -	35.82 -	35.77 -
TBOFS	10 10	0.09 -	0.06 -	35.84 -	35.85 -
TBOFS	20 22	0.09 -	0.06 -	35.95 -	36.01 -

Table 5.4. Water Temperature Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 5/16/2011. G-NCOM predictions are in row 1 at every 10^{th} OFS grid point. No RTOFS predictions are available.

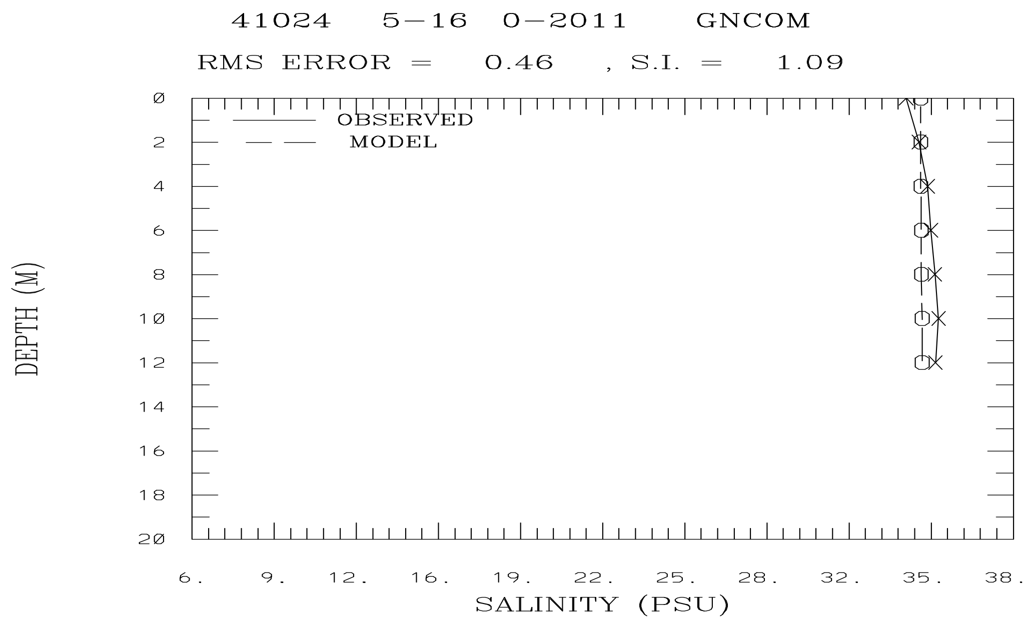
OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.91 -	0.25 -	14.37 -	13.69 -
DBOFS	30 30	1.33 -	0.22 -	12.93 -	11.70 -
DBOFS	81 81	1.79 -	0.18 -	11.43 -	10.02 -
CBOFS	0 0	0.86 -	0.30 -	16.04 -	15.54 -
CBOFS	15 17	1.54 -	0.38 -	14.78 -	13.95 -
CBOFS	36 39	2.56 -	0.53 -	13.67 -	11.97 -
TBOFS	0 0	1.68 -	0.81 -	26.74 -	25.11 -
TBOFS	10 10	2.06 -	0.65 -	26.65 -	24.61 -
TBOFS	20 22	2.30 -	0.53 -	25.75 -	23.54 -

Table 5.5. U (East) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 5/16/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	14.89 -	0.66 -	12.09 -	1.00 -	17.65 -	5.30 -	9.60 -
DBOFS	30 30	13.02 -	0.63 -	11.33 -	0.95 -	14.97 -	5.30 -	9.29 -
DBOFS	81 81	9.48 -	0.46 -	8.86 -	072 -	11.92 -	5.30 -	8.56 -
CBOFS	0 0	12.67 -	0.57 -	15.06 -	1.00 -	19.32 -	10.17 -	8.24 -
CBOFS	15 17	11.84 -	0.70 -	11.48 -	1.00 -	8.60 -	10.17 -	8.26 -
CBOFS	36 39	14.23 -	0.84 -	11.20 -	0.95 -	1.23 -	10.17 -	7.89 -
TBOFS	0 0	7.10 -	0.73 -	7.32 -	1.00 -	8.35 -	2.50 -	1.54 -
TBOFS	10 10	6.09 -	0.76 -	5.87 -	0.99 -	6.15 -	2.50 -	1.59 -
TBOFS	20 22	9.29 -	0.76 -	9.64 -	1.00 -	10.11 -	2.50 -	1.59 -

Table 5.6. V (North) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 5/16/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	14.22 -	0.71 -	13.30 -	1.00 -	16.52 -	6.71 -	8.21 -
DBOFS	30 30	9.71 -	0.61 -	9.47 -	0.96 -	8.60 -	6.71 -	8.24 -
DBOFS	81 81	7.66 -	0.53 -	7.91 -	0.78 -	4.75 -	6.71 -	7.81 -
CBOFS	0 0	31.31 -	0.90 -	32.17 -	1.00 -	35.26 -	7.20 -	6.70 -
CBOFS	15 17	15.10 -	0.83 -	14.92 -	0.96 -	18.88 -	7.20 -	7.40 -
CBOFS	36 39	11.52 -	0.73 -	11.51 -	0.98 -	16.18 -	7.20 -	7.77 -
TBOFS	0 0	6.03 -	0.79 -	7.00 -	1.00 -	2.86 -	1.54 -	-1.61 -
TBOFS	10 10	9.23 -	0.84 -	11.38 -	1.00 -	7.77 -	1.54 -	-1.64 -
TBOFS	20 22	4.99 -	0.77 -	5.91 -	1.00 -	2.01 -	1.54 -	-1.63 -



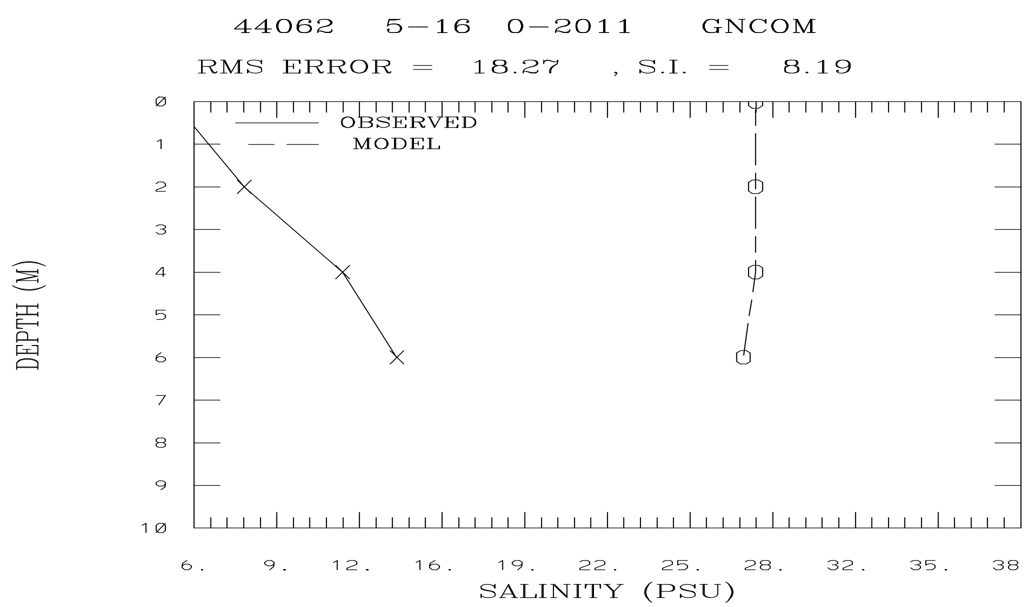


Figure 5.1. G-NCOM salinity forecast profile at Stations 41024 and 44062 data versus model comparisons on May 16, 2011 at hr 00 UTC.

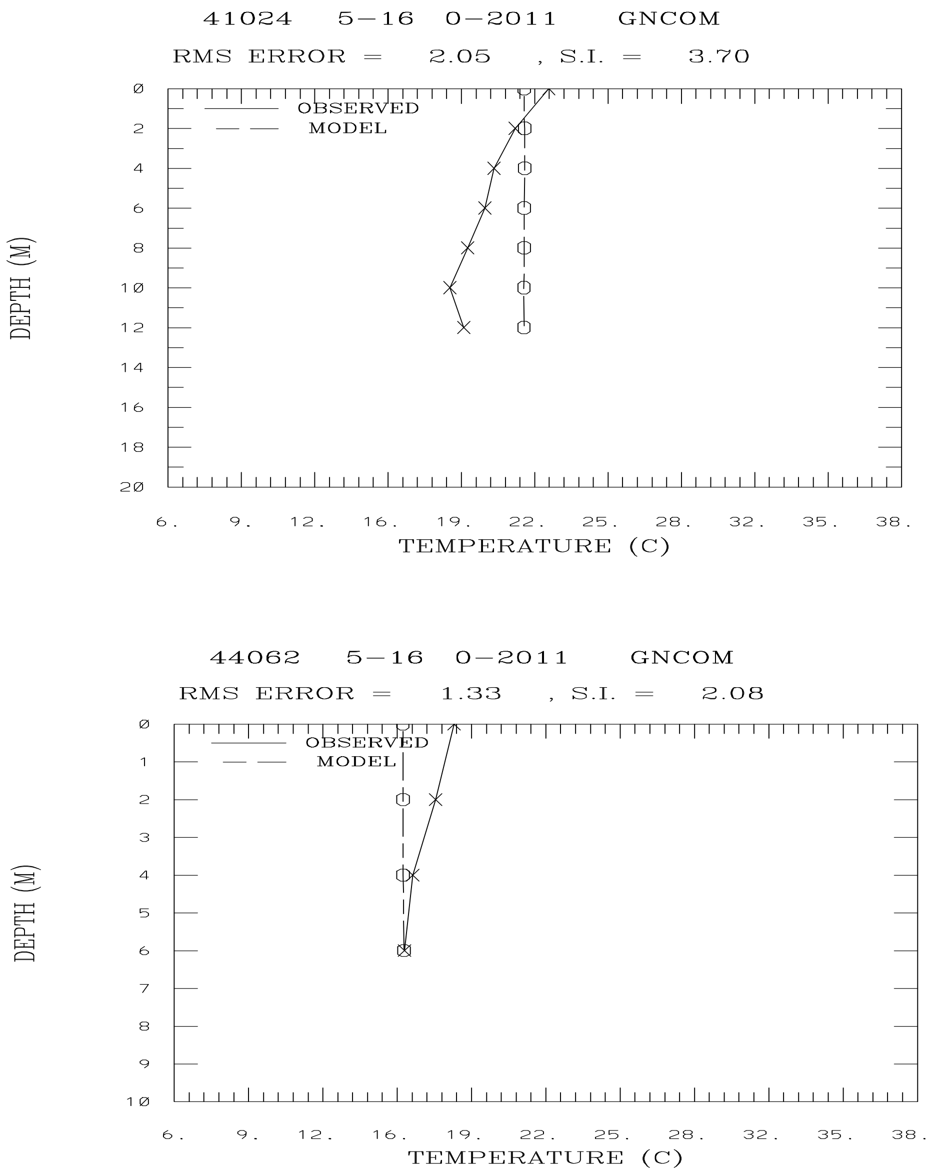
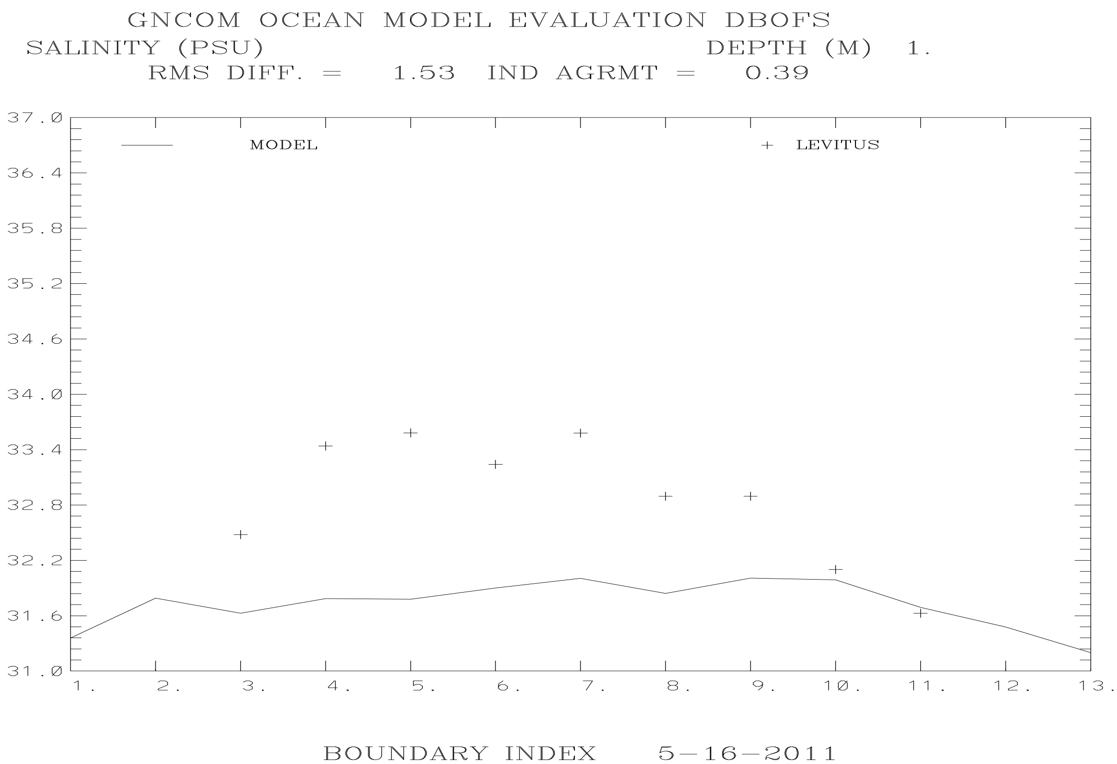


Figure 5.2. G-NCOM water temperature forecast profile at Stations 41024 and 44062 data versus model comparisons on May 16, 2011 at hr 00 UTC.



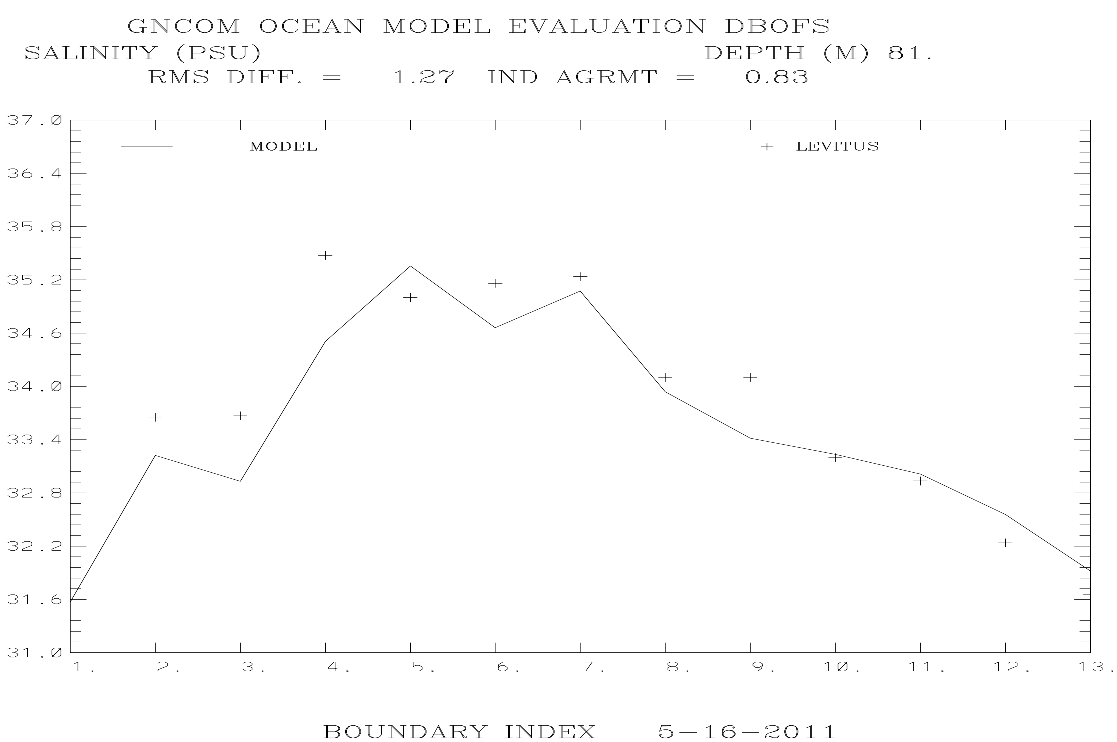
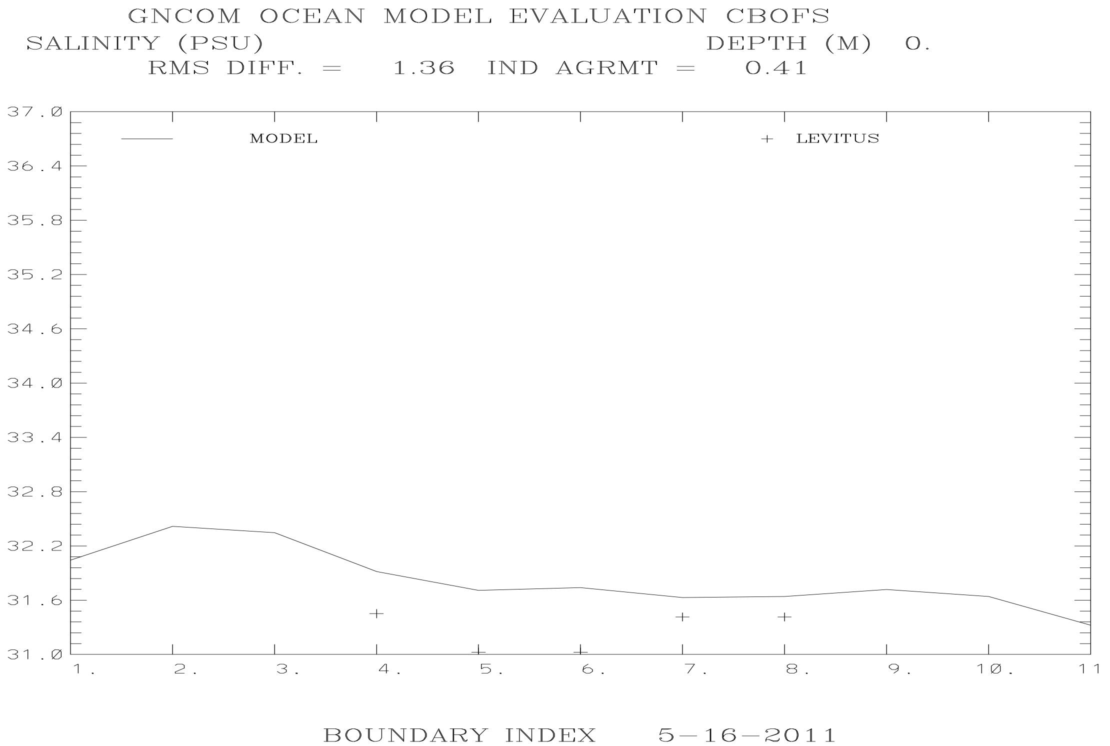


Figure 5.3. GNCOM surface and near bottom salinity at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



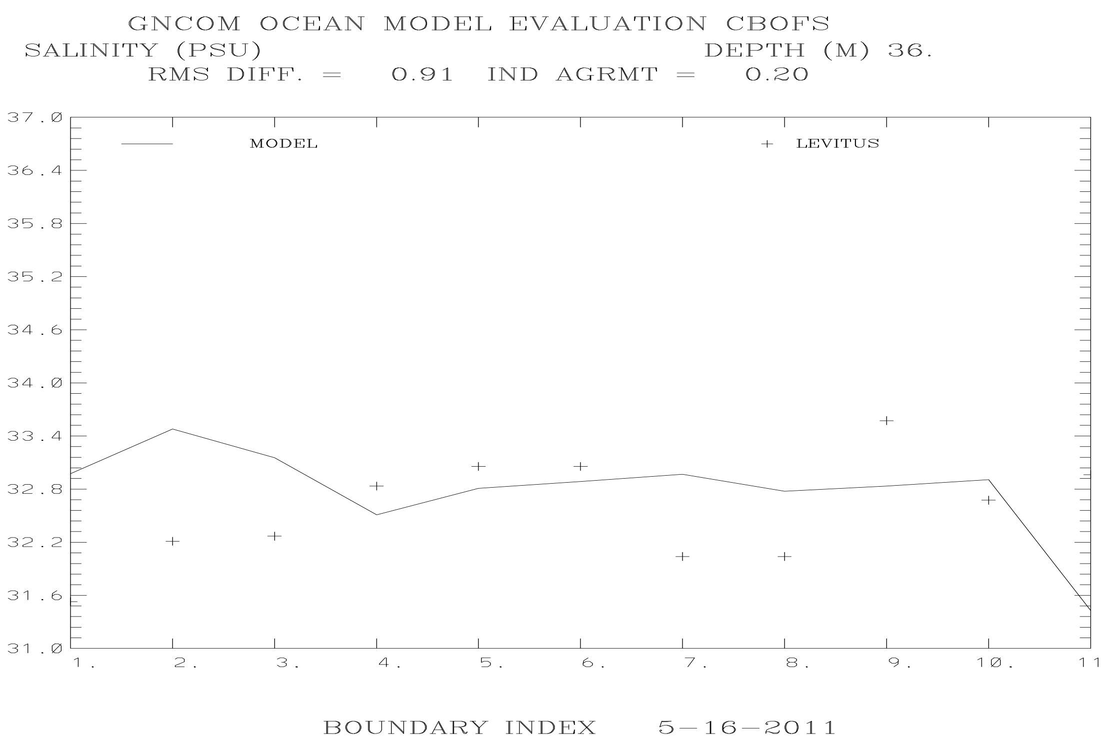
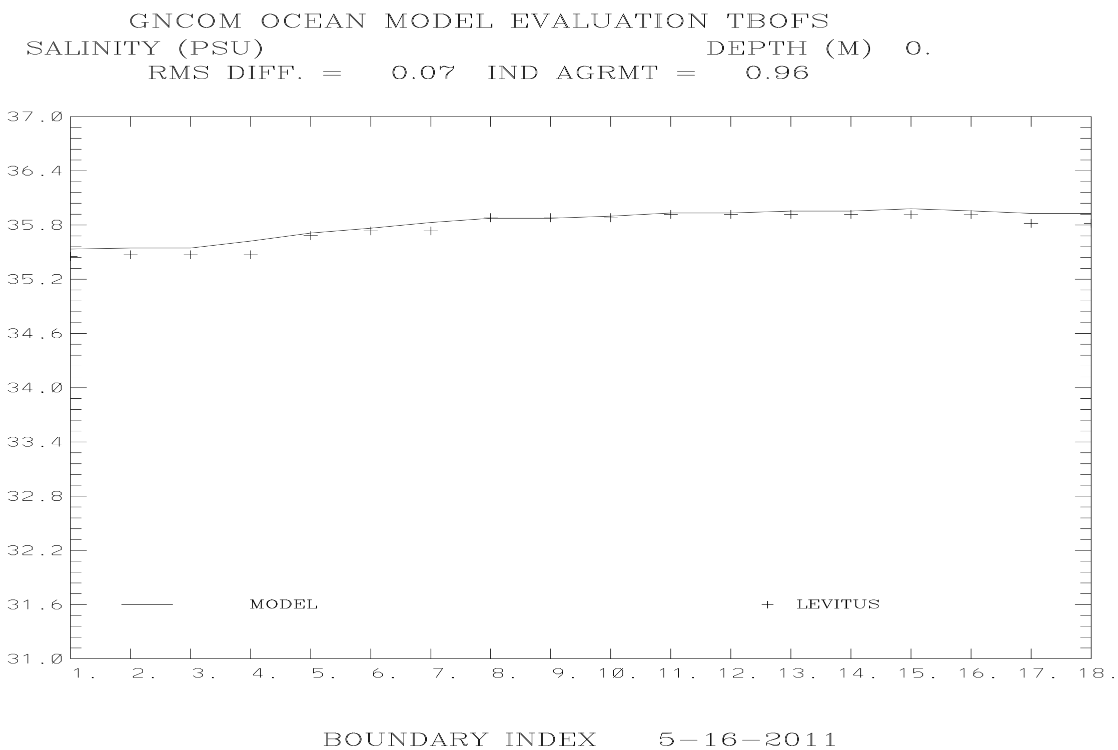


Figure 5.4. GNCOM surface and near bottom salinity at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



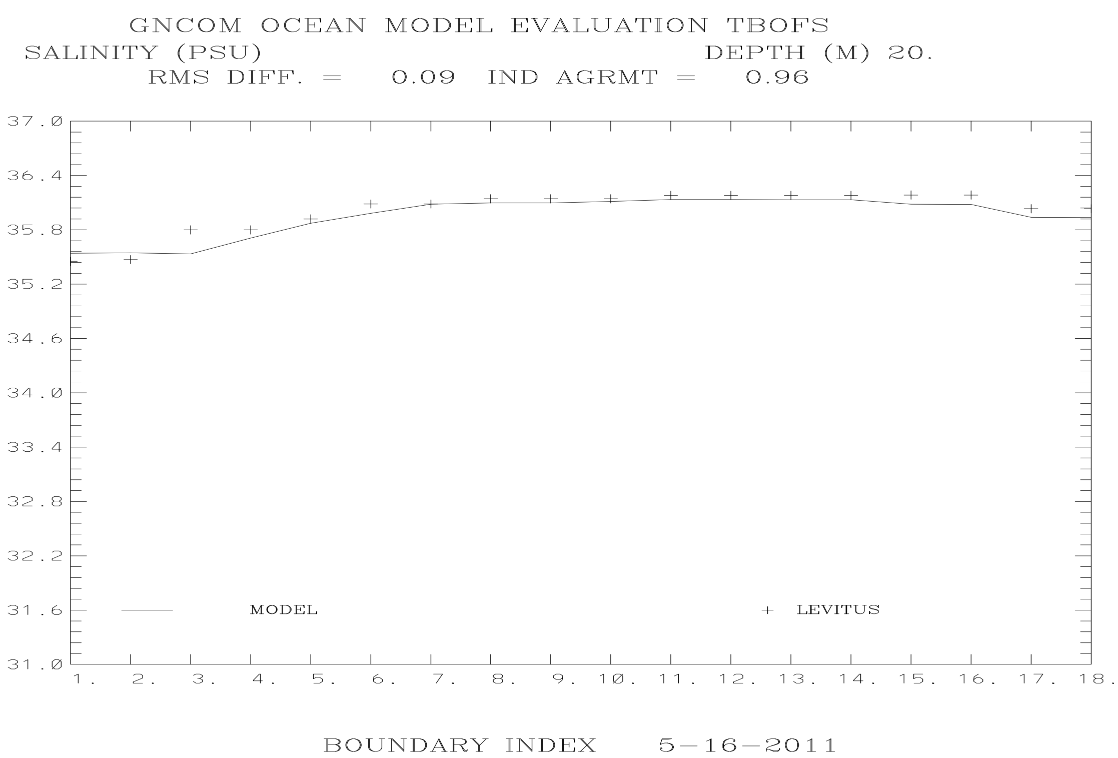
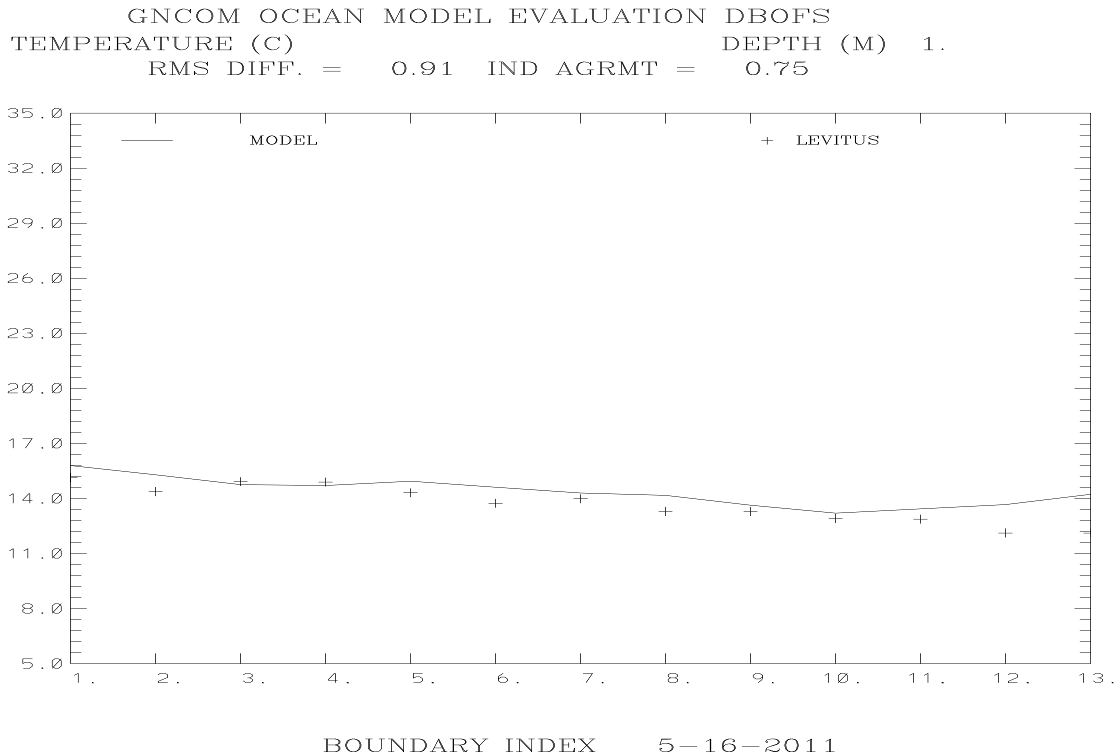


Figure 5.5. GNCOM surface and near bottom salinity at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.



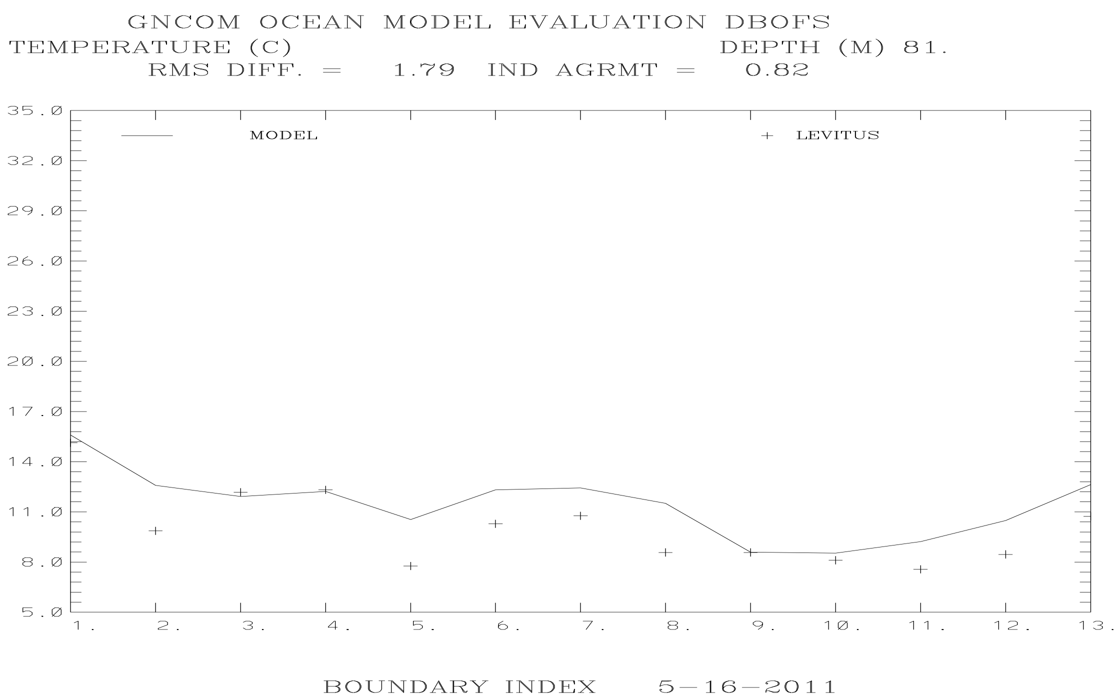
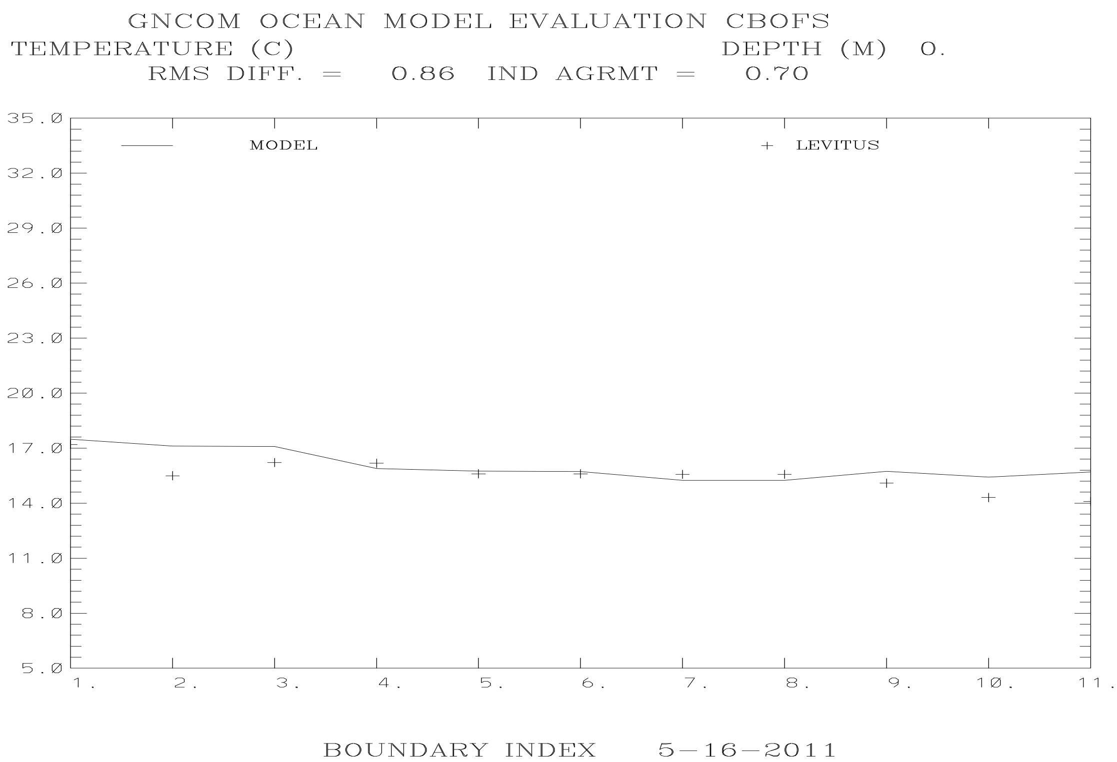


Figure 5.6. GNCOM surface and near bottom water temperature at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



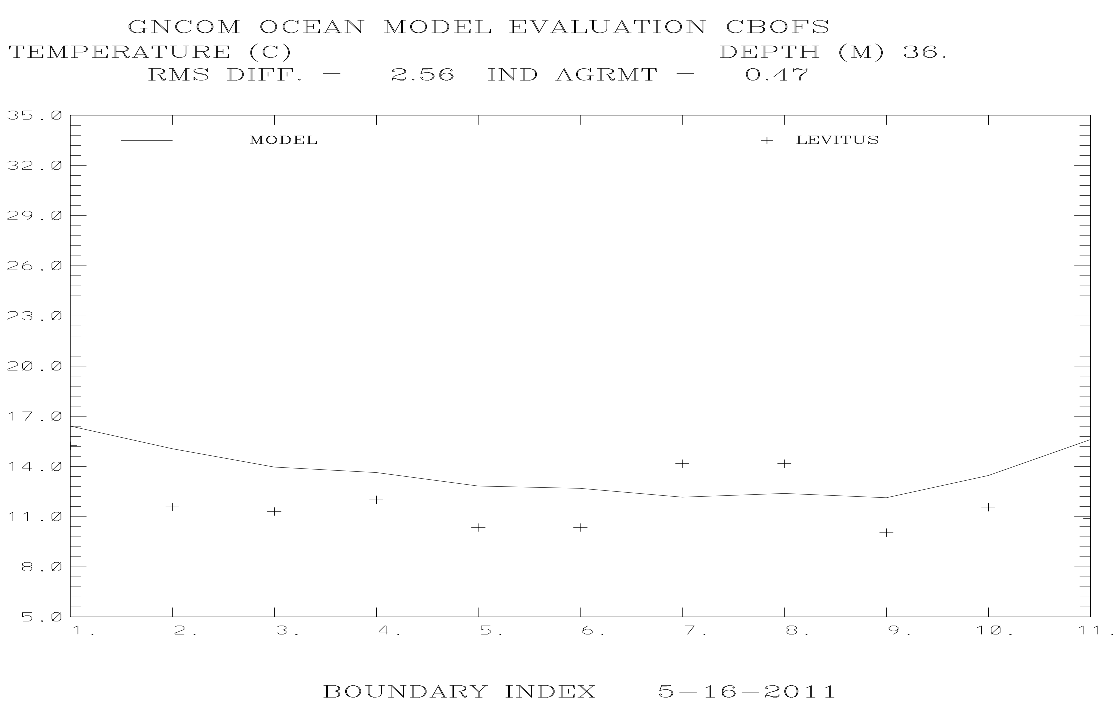
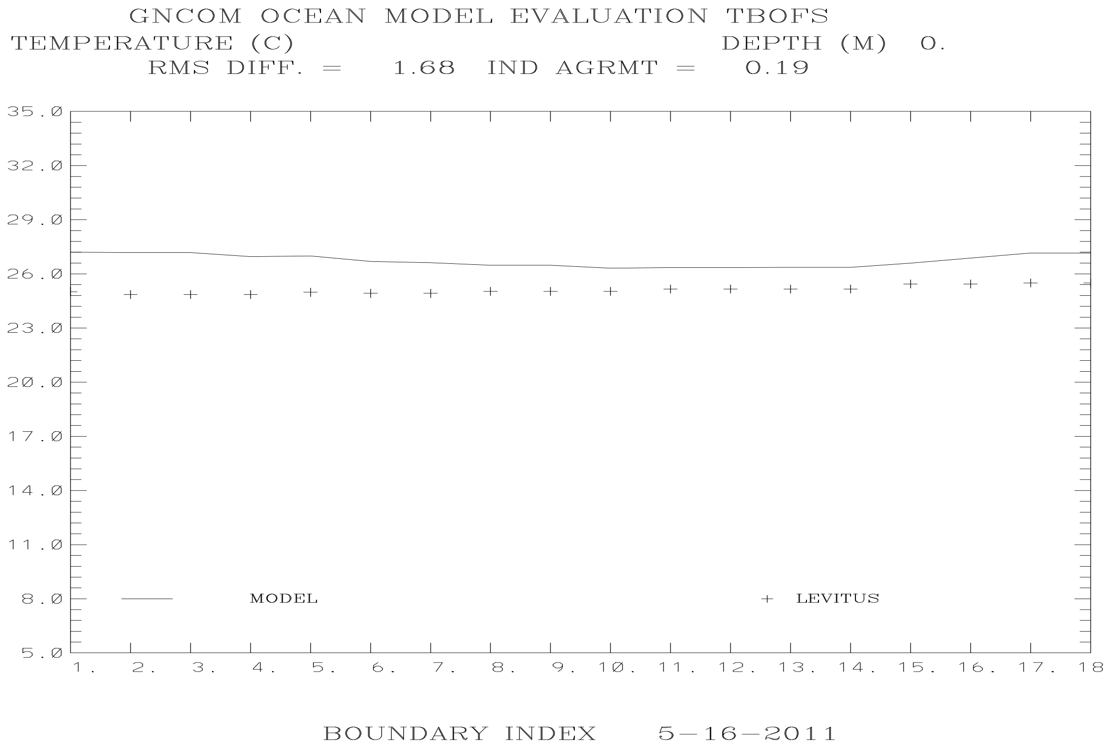


Figure 5.7. GNCOM surface and near bottom water temperature at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



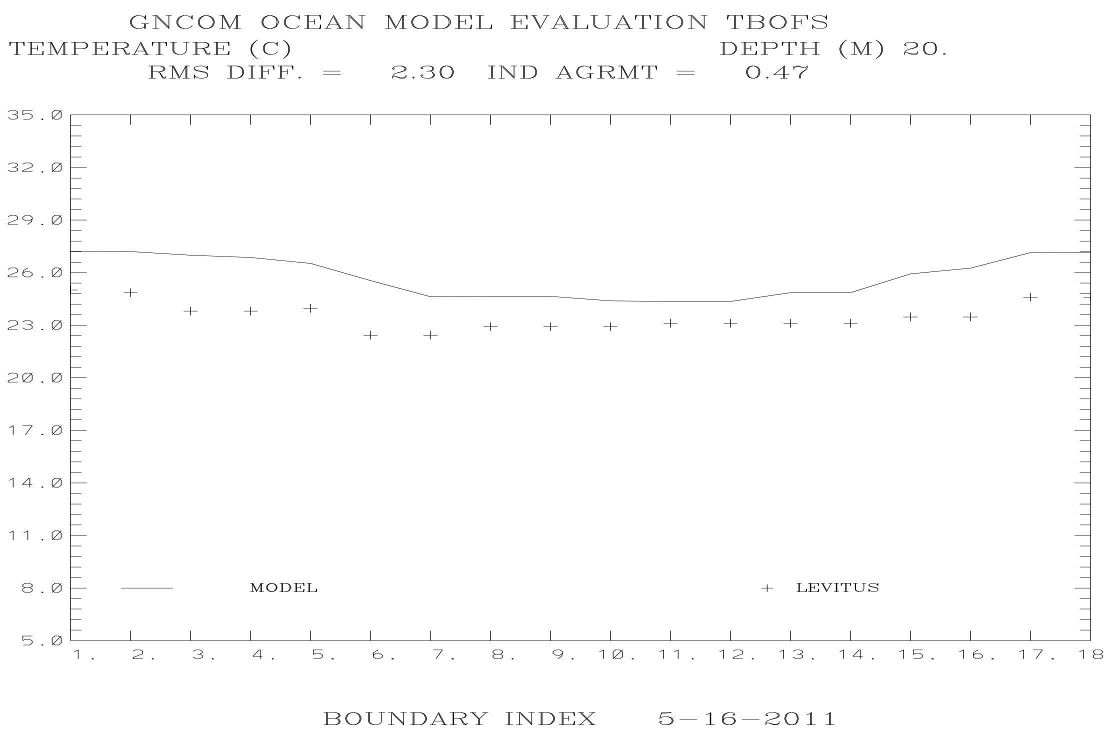
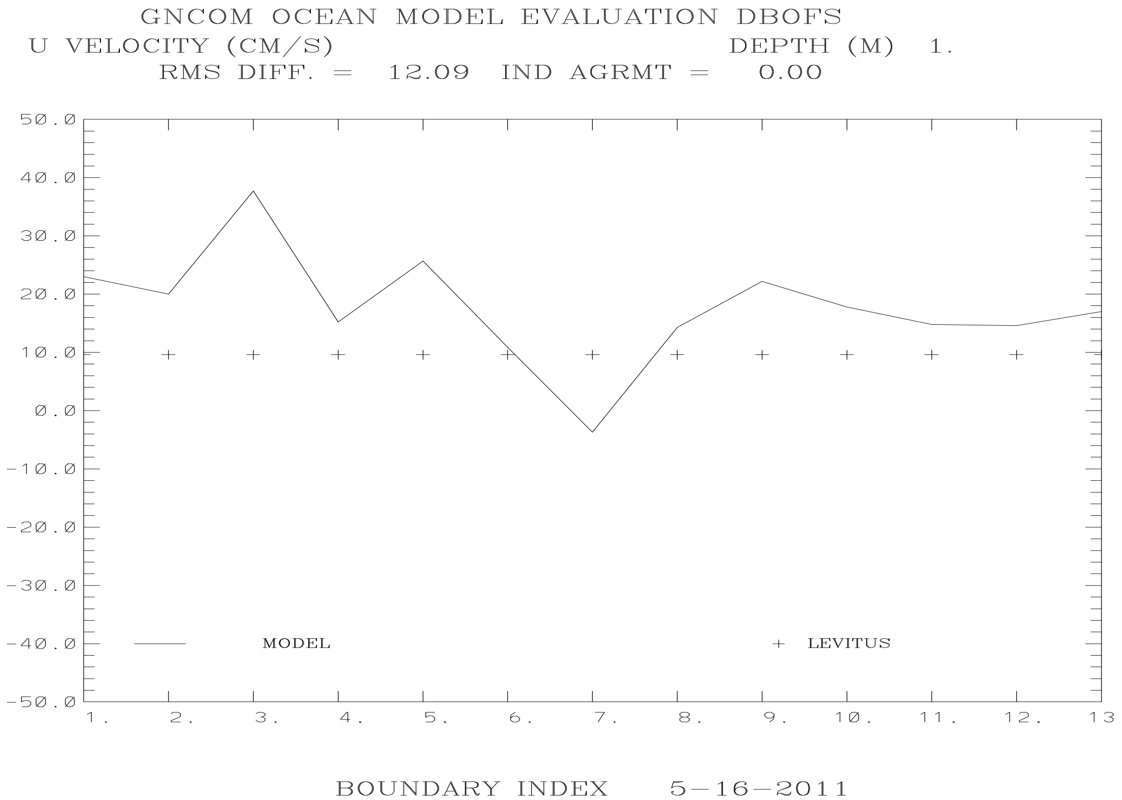


Figure 5.8. GNCOM surface and near bottom water temperature at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



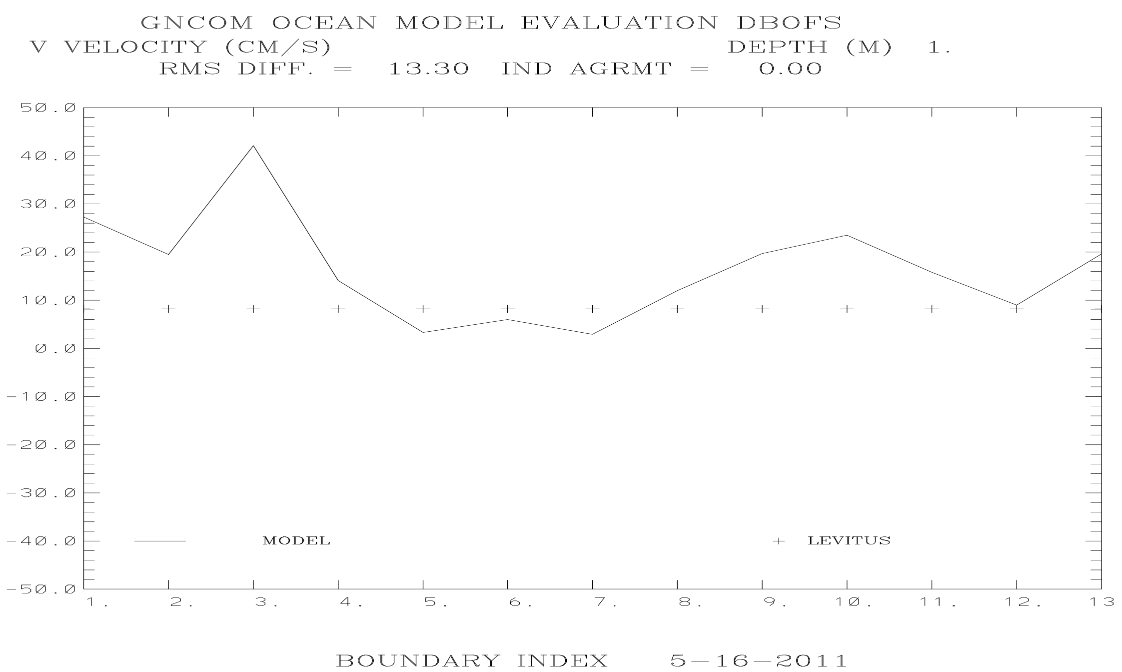
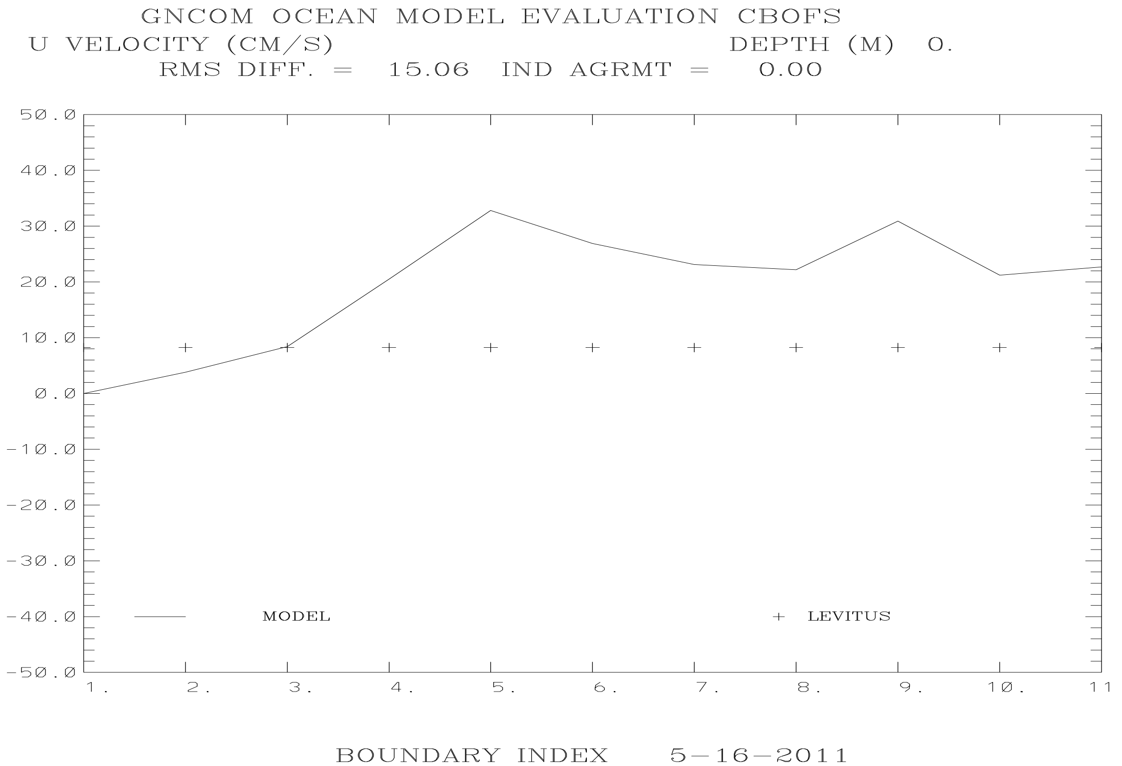


Figure 5.9. GNCOM surface U (East) and V (North) components at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



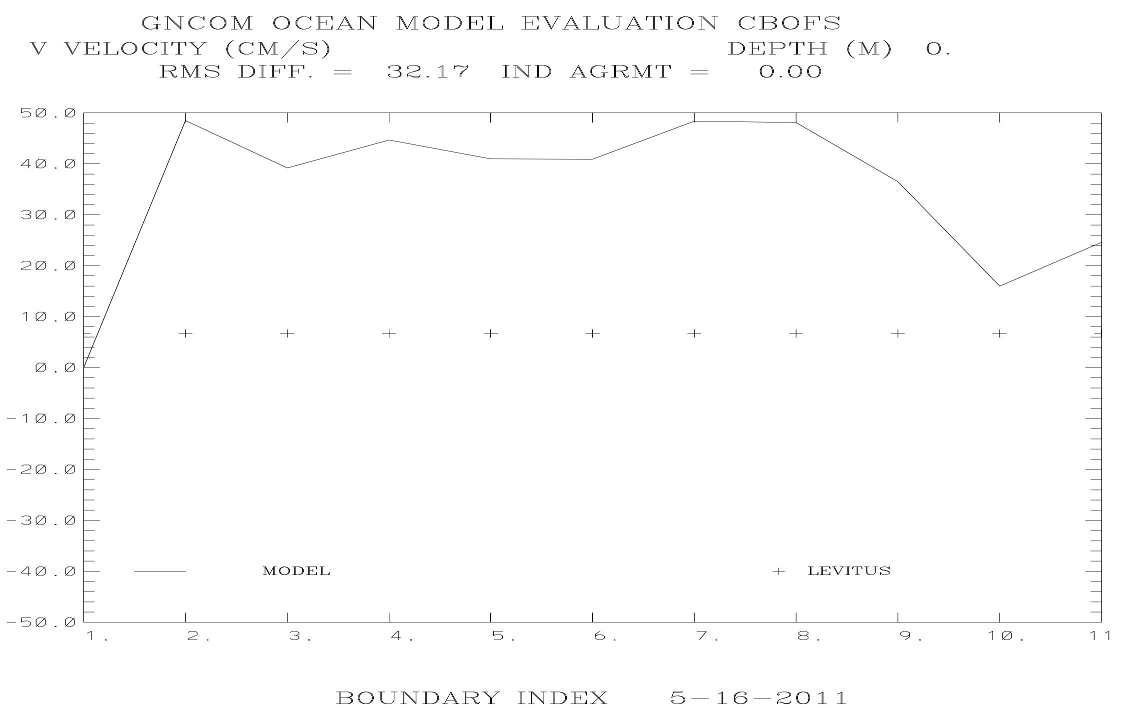
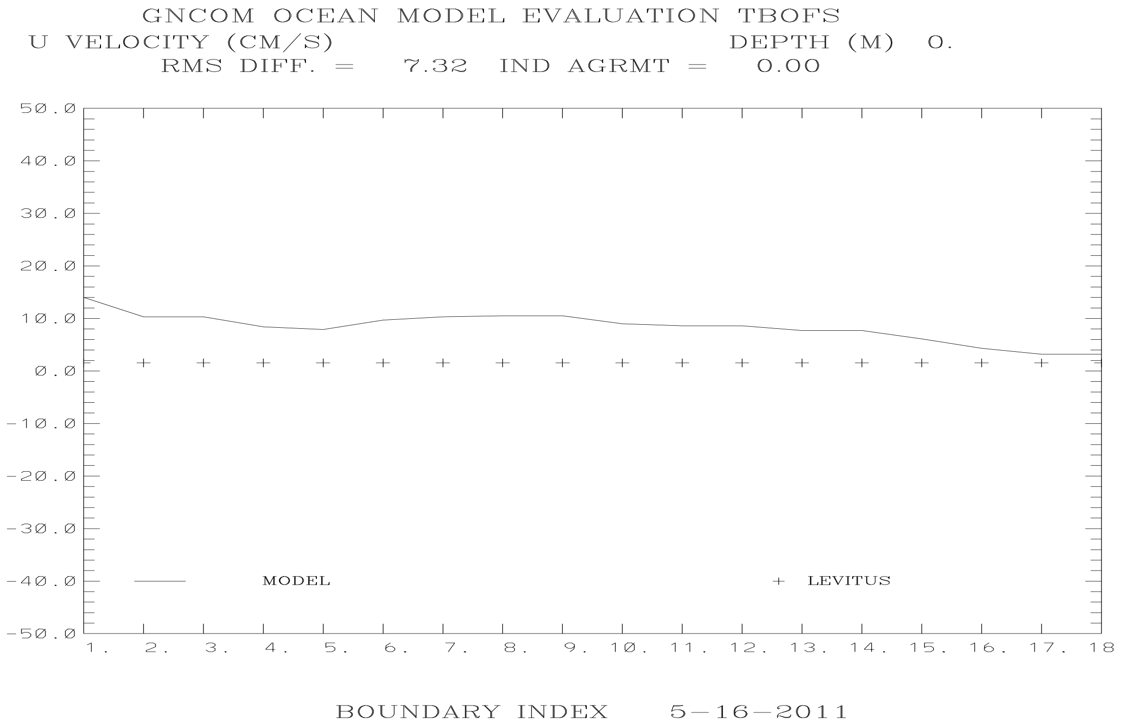


Figure 5.10. GNCOM surface U (East) and V (North) components at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



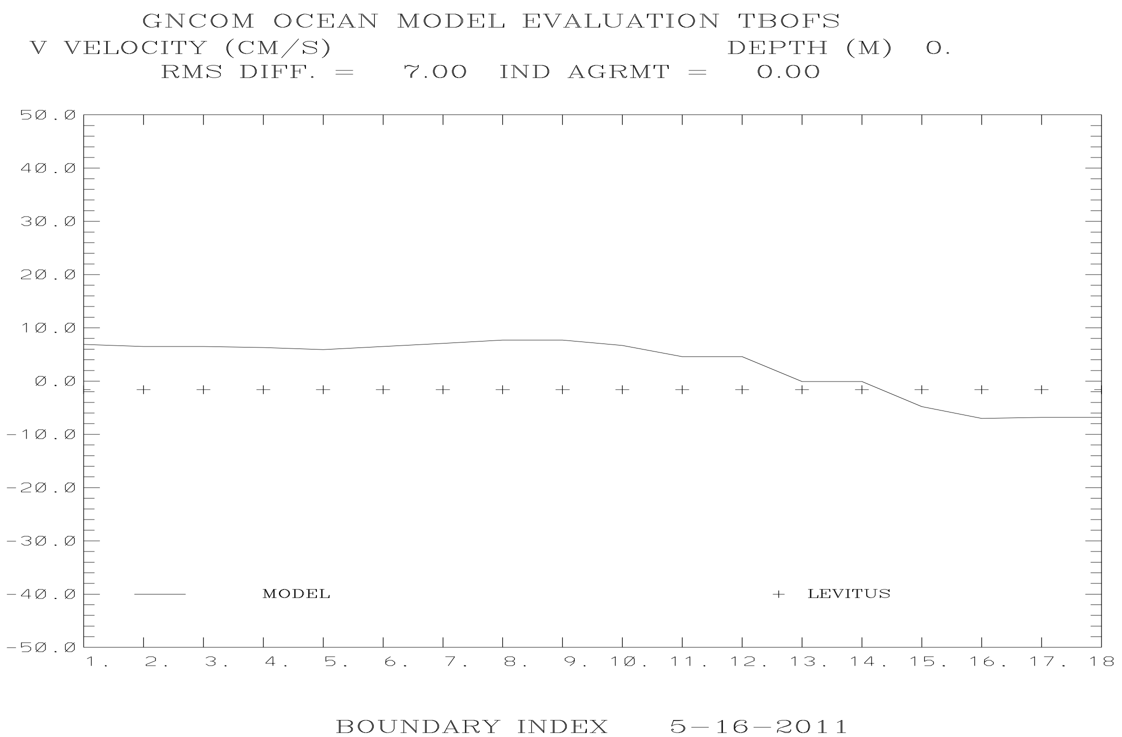


Figure 5.11. GNCOM surface U (East) and V (North) components at the start of the 5/16/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.

6. AUGUST 2011 MONTHLY ANALYSIS

During August 2011, only the G-NCOM ocean model 00 UTC nowcast/forecast cycles were accessed to provide daily snapshots on August 14 and 15, 2011. RTOFS forecasts were not available from the new NOMADS server. Both G-NCOM cycles were analyzed with the results for both daily snapshots being very similar. As a result, we show here the G-NCOM results for August 14th only.

In Table 6.1 for water temperature and in Table 6.2 for salinity, the G-NCOM predictions are compared with the TESAC CTD profiles at two locations. It should be noted, that the purpose of these comparisons is to provide an initial spot check on the integrity of the ocean model vertical density structure. Within the analysis only every 10th CTD profile is considered. In Figures 6.1 and 6.2, the salinity and water temperature profile comparisons at Station 41024 offshore of the North Carolina/South Carolina border are shown, respectively. Note the stratification index shown corresponds to Stratification Index One. In general, the G-NCOM ocean model profiles are vertically well-mixed, while more stratification is noted in the observed salinity profiles. Note the same Station 41024 is given with the same time stamp but with a slightly different observed profile.

In Table 6.3, the ocean model salinity responses along the three NOS OFS boundaries are presented. The analysis considers every 10th ocean model boundary point. Note for DBOFS, CBOFS, and TBOFS the number of boundary points is 128, 106, and 176, respectively. The G-NCOM response is compared relative to the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 6.3 (DBOFS), Figure 6.4 (CBOFS), and in Figure 6.5 (TBOFS), the G-NCOM surface and near bottom salinity ocean model responses corresponded closely to climatology except along the CBOFS open boundary.

In Table 6.4, the G-NCOM water temperature responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative the WOA 2001 climatology. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to WOA 2001 climatology. The ocean model and data mean corresponding to climatology are given. As may be seen in Figure 6.6 (DBOFS), Figure 6.7 (CBOFS), and in Figure 6.8 (TBOFS), the surface responses corresponded more closely to climatology than the near bottom water temperature response except along the TBOFS open boundary.

In Table 6.5, the G-NCOM U (East) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity. The G-NCOM, ADCIRC mean and WOA 2001 means are given. As may be seen in the top half of Figure 6.9 (DBOFS) , Figure 6.10 (CBOFS), and in Figure 6.11

(TBOFS), the G-NCOM surface U (East) velocity component ocean model responses are quite different along the DBOFS and CBOFS open boundaries relative to WOA 2001 climatology, which is labeled Levitus.

In Table 6.6, the G-NCOM V (North) velocity component responses along the three NOS OFS boundaries are presented. Again the analysis considers every 10th ocean model boundary point. The responses are compared relative to a thermal wind estimate using the WOA 2001 climatology as well as from a reconstruction of the vertically integrated tidal velocity from the ADCIRC tidal inversion. Results are given at three depths for each of the three OFSs. The RMS difference and Willmott et al. (1985) relative differences are given relative to thermal wind estimate and the ADCIRC derived tidal velocity. The ocean model, ADCIRC mean and WOA 2001 means are given. As may be seen in lower half of Figure 6.9 (DBOFS) , Figure 6.10 (CBOFS), and in Figure 6.11 (TBOFS), the G-NCOM surface V (North) velocity component ocean model responses are quite different along all the DBOFS and CBOFS OFS open boundaries relative to WOA 2001 climatology, which is labeled Levitus.

Table 6.1. Water Temperature (^{o}C) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data August 2011. G-NCOM predictions are given in row 1 and no RTOFS predictions are available. Note SC/NC-ATL=South/North Carolina Atlantic.

Station	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41024 SC/NC-ATL	8/14:0	12 -	1.57 -	28.29 -	29.44 -	28.41 -	26.62 -	2.71 -	0.10 -
41024 SC/NC-ATL	8/14:0	12 -	1.55 -	28.29 -	29.21 -	28.41 -	26.62 -	2.48 -	0.09 -

Table 6.2. Salinity (PSU) Comparisons of G-NCOM and RTOFS Predictions with NBDC Buoy Data August 2011. G-NCOM predictions are given in row 1 and no RTOFS predictions are available. Note SC/NC-ATL=South/North Carolina Atlantic.

Station	Time (hr)	Depth (m)	RMS Difference	Surface Model	Surface Data	Bottom Model	Bottom Data	S.I. 1	S.I. 2
41024 SC/NC-ATL	8/14:0	12 -	0.59 -	35.88 -	35.86 -	35.91 -	35.30 -	0.54 -	0.02 -
41024 SC/NC-ATL	8/14:0	12 -	0.60 -	35.88 -	35.64 -	35.91 -	35.30 -	0.32 -	0.01 -

Table 6.3. Salinity Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 8/14/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	0.95 -	0.32 -	32.18 -	31.78 -
DBOFS	30 30	0.99 -	0.10 -	33.26 -	32.67 -
DBOFS	81 81	1.26 -	0.16 -	34.23 -	33.43 -
CBOFS	0 0	1.65 -	0.66 -	32.48 -	30.92 -
CBOFS	15 17	1.67 -	0.51 -	33.40 -	31.76 -
CBOFS	36 39	1.77 -	0.74 -	34.39 -	32.81 -
TBOFS	0 0	0.51 -	0.64 -	34.88 -	35.34 -
TBOFS	10 10	0.55 -	0.54 -	35.03 -	35.55 -
TBOFS	20 22	0.47 -	0.30 -	35.54 -	35.89 -

Table 6.4. Water Temperature Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 8/14/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

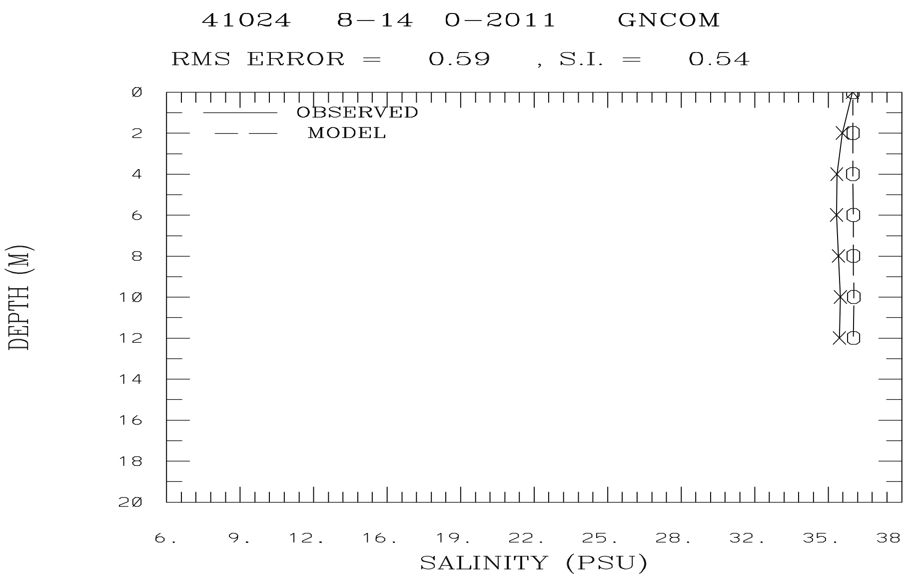
NOS OFS Name	Mean Depth (m)	RMS Difference	Relative Difference	Ocean Model Mean	Data Mean
DBOFS	1 1	1.42 -	0.52 -	17.64 -	18.93 -
DBOFS	30 30	1.45 -	0.18 -	16.48 -	17.42 -
DBOFS	81 81	1.99 -	0.13 -	14.17 -	14.38 -
CBOFS	0 0	1.45 -	0.65 -	18.33 -	19.67 -
CBOFS	15 17	1.60 -	0.61 -	18.14 -	19.58 -
CBOFS	36 39	2.61 -	0.49 -	16.83 -	18.68 -
TBOFS	0 0	0.17 -	0.13 -	26.42 -	26.55 -
TBOFS	10 10	0.49 -	0.53 -	26.01 -	26.45 -
TBOFS	20 22	0.31 -	0.55 -	26.03 -	26.20 -

Table 6.5. U (East) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 8/14/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	11.64 -	0.72 -	8.27 -	1.00 -	13.86 -	4.56 -	11.73 -
DBOFS	30 30	9.77 -	0.63 -	15.56 -	0.94 -	-1.76 -	4.56 -	11.59 -
DBOFS	81 81	10.09 -	0.68 -	15.50 -	0.85 -	-3.61 -	4.56 -	10.74 -
CBOFS	0 0	15.92 -	0.90 -	16.43 -	1.00 -	-0.92 -	8.38 -	11.09 -
CBOFS	15 17	18.91 -	0.93 -	20.09 -	1.00 -	-5.38 -	8.38 -	11.31 -
CBOFS	36 39	21.37 -	0.92 -	22.69 -	0.98 -	-9.32 -	8.38 -	11.18 -
TBOFS	0 0	7.02 -	0.70 -	5.76 -	1.00 -	-0.43 -	2.63 -	0.50 -
TBOFS	10 10	5.89 -	0.87 -	5.28 -	0.97 -	3.48 -	2.63 -	0.57 -
TBOFS	20 22	7.20 -	0.70 -	5.53 -	0.99 -	-3.28 -	2.63 -	0.68 -

Table 6.6. V (North) Velocity Component Comparisons of G-NCOM and RTOFS predictions against World Ocean Atlas 2001 Climatology on 8/14/2011. G-NCOM predictions are in row 1 at every 10th OFS grid point. No RTOFS predictions are available.

NOS OFS Name	Mean Depth (m)	ADCIRC RMS Difference	ADCIRC Relative Difference	WOA2001 RMS Difference	WOA2001 Relative Difference	Ocean Model Mean	ADCIRC Mean	WOA 2001 Mean
DBOFS	1 1	19.74 -	0.89 -	17.52 -	1.00 -	21.92 -	5.62 -	8.31 -
DBOFS	30 30	14.39 -	0.93 -	13.88 -	0.97 -	7.42 -	5.62 -	8.56 -
DBOFS	81 81	10.47 -	0.85 -	9.60 -	0.75 -	6.40 -	5.62 -	8.08 -
CBOFS	0 0	32.04 -	0.92 -	29.66 -	1.00 -	34.20 -	4.10 -	6.93 -
CBOFS	15 17	14.78 -	0.85 -	11.76 -	0.95 -	17.44 -	4.10 -	7.62 -
CBOFS	36 39	12.53 -	0.80 -	9.44 -	0.96 -	15.65 -	4.10 -	7.93 -
TBOFS	0 0	9.53 -	0.80 -	6.50 -	1.00 -	-7.12 -	2.15 -	-0.80 -
TBOFS	10 10	5.08 -	0.68 -	4.72 -	0.89 -	0.79 -	2.15 -	-0.61 -
TBOFS	20 22	3.88 -	0.72 -	3.24 -	0.91 -	0.93 -	2.15 -	-0.47 -



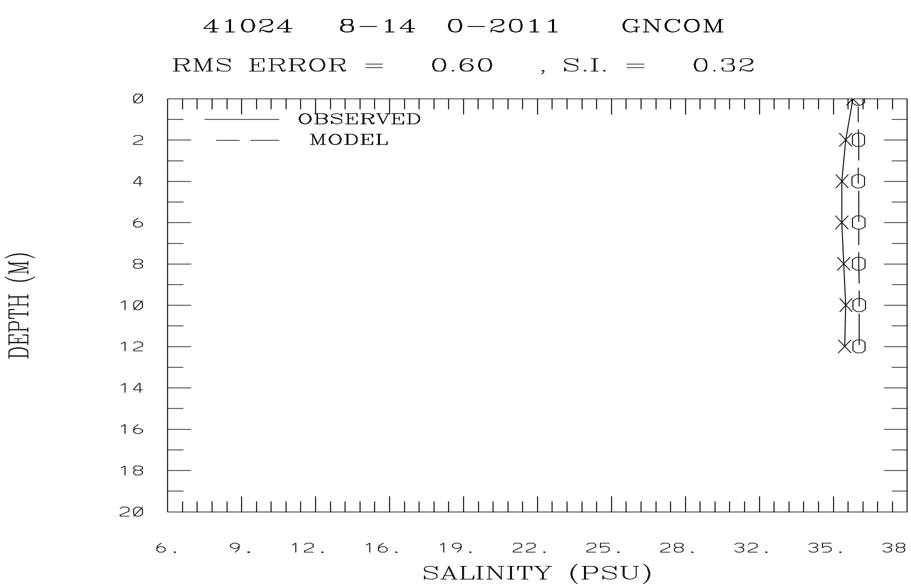
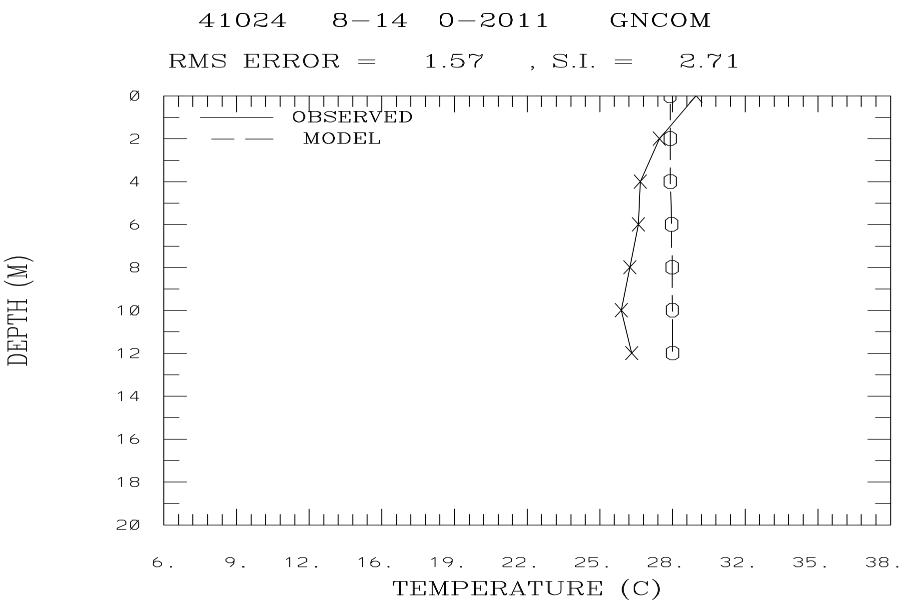


Figure 6.1. G-NCOM salinity forecast profile at Station 41024 data versus model comparisons on August 14, 2011 near hr 00 UTC.



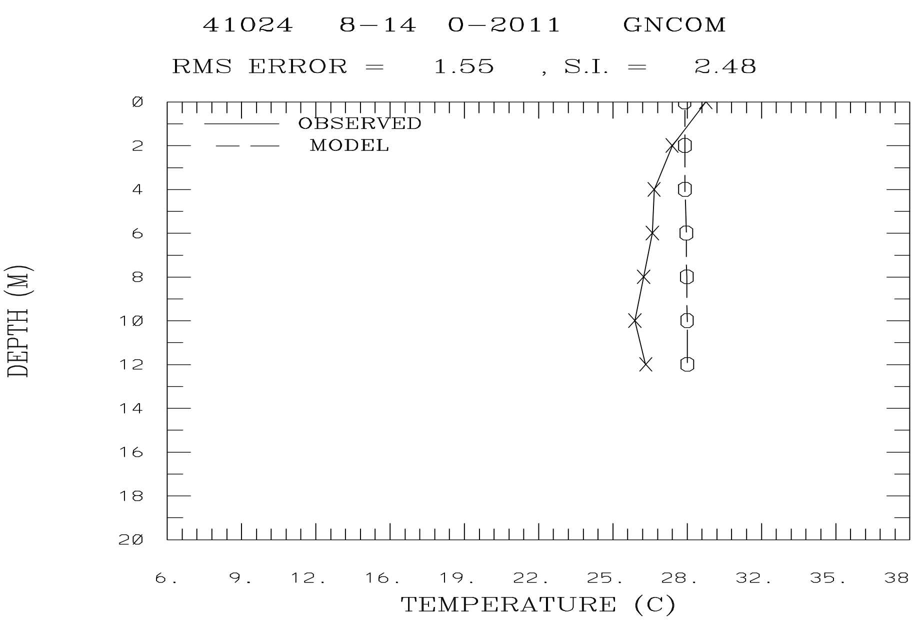
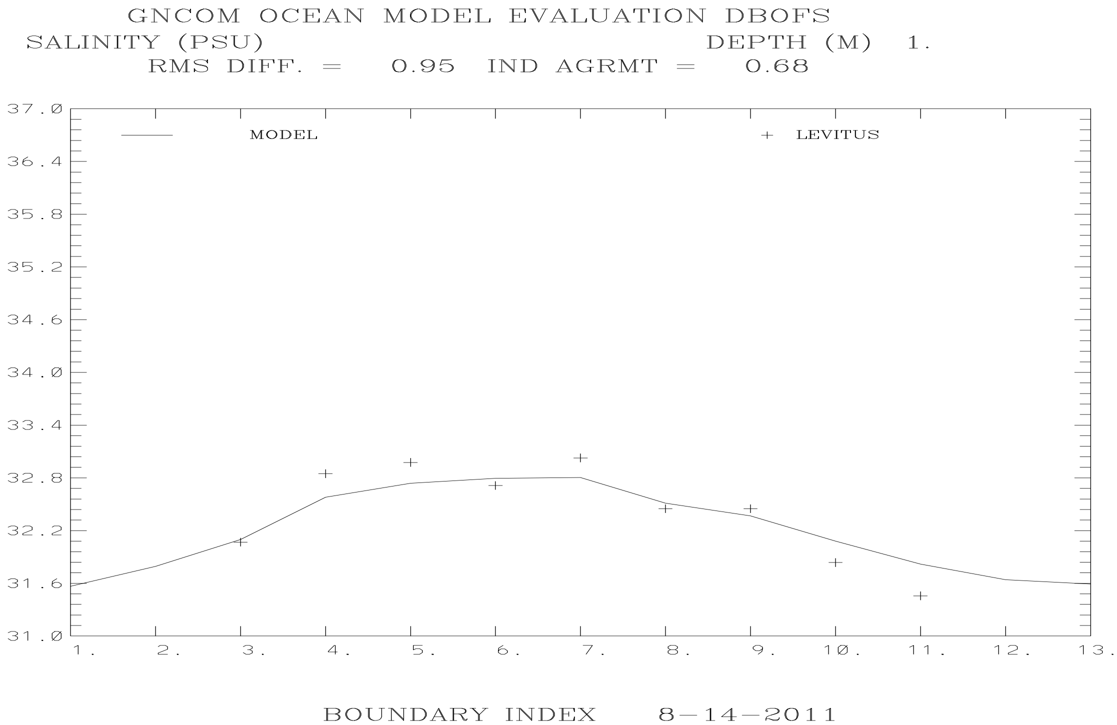


Figure 6.2. G-NCOM water temperature forecast profile at Station 41024 data versus model comparisons on August 14, 2011 near hr 00 UTC.



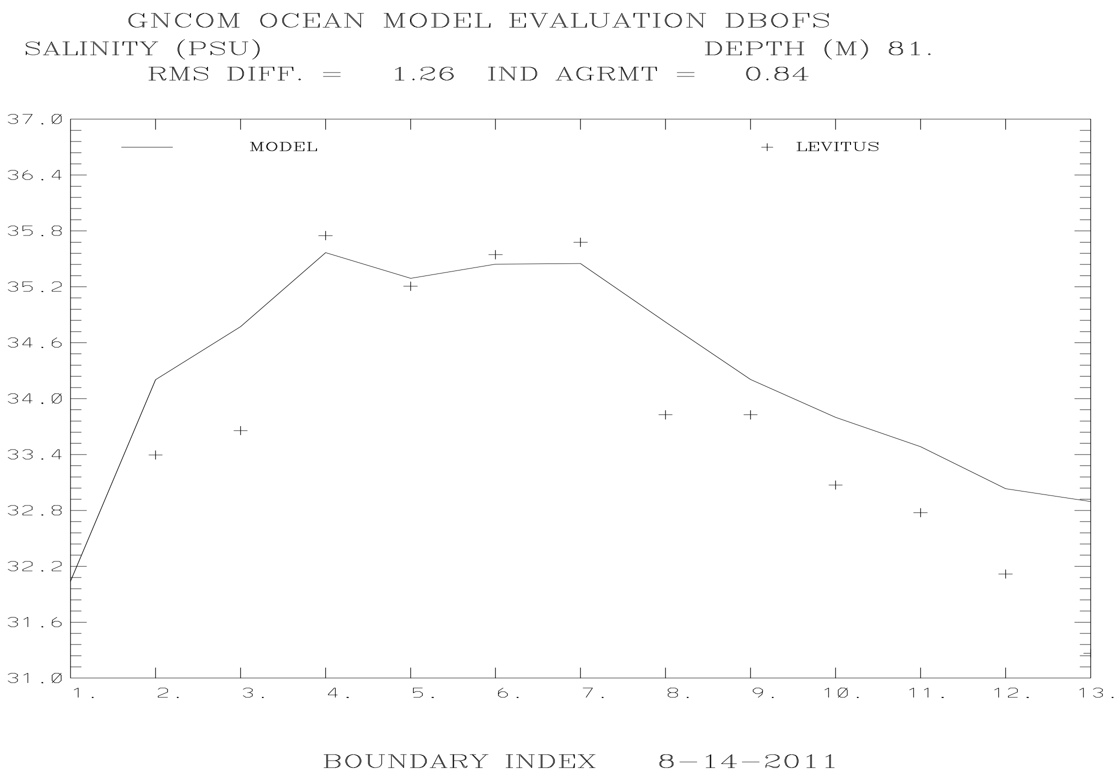
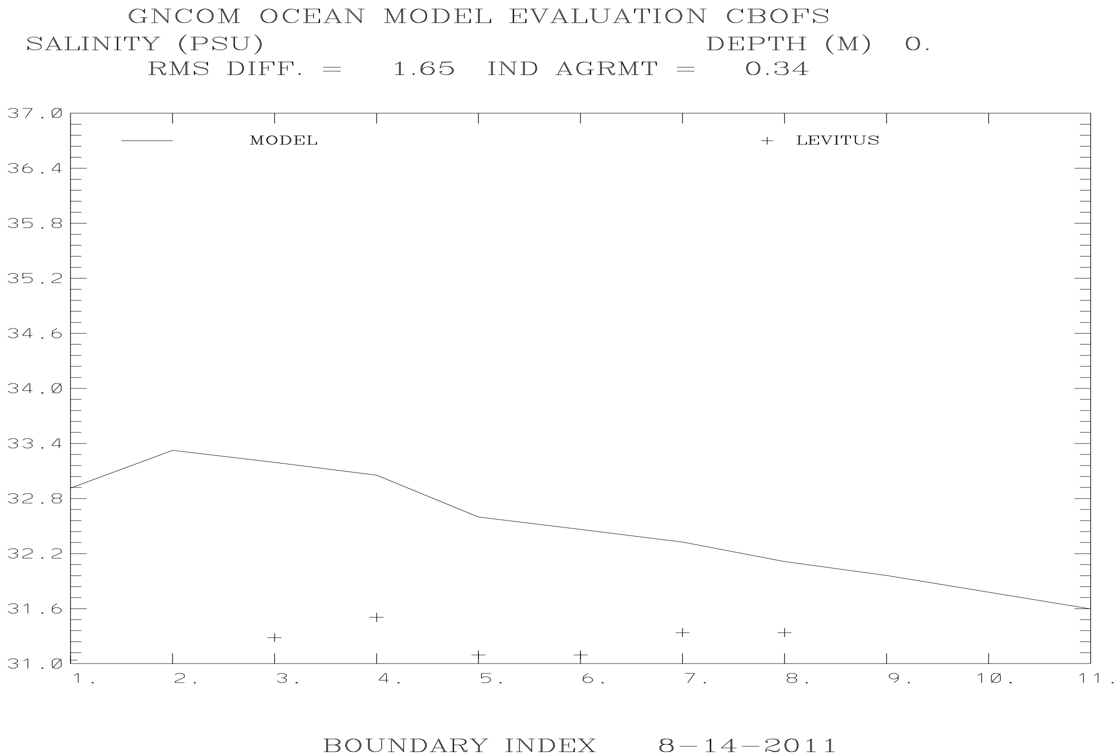


Figure 6.3. GNCOM surface and near bottom salinity at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



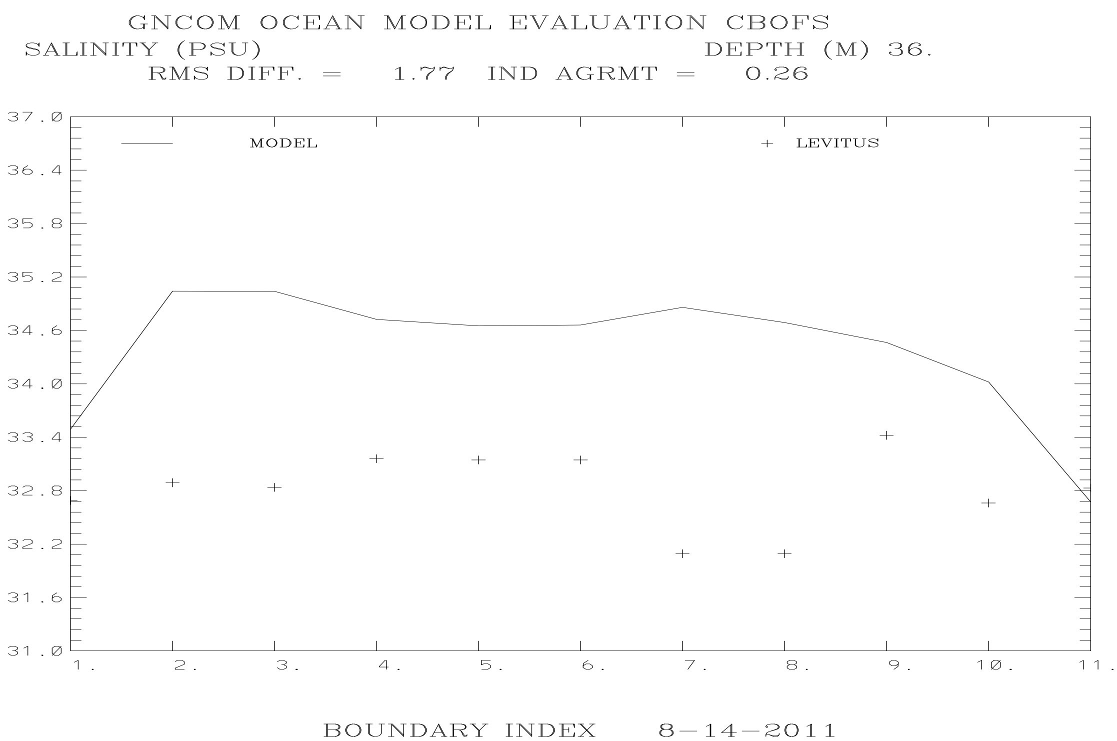


Figure 6.4. GNCOM surface and near bottom salinity at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.

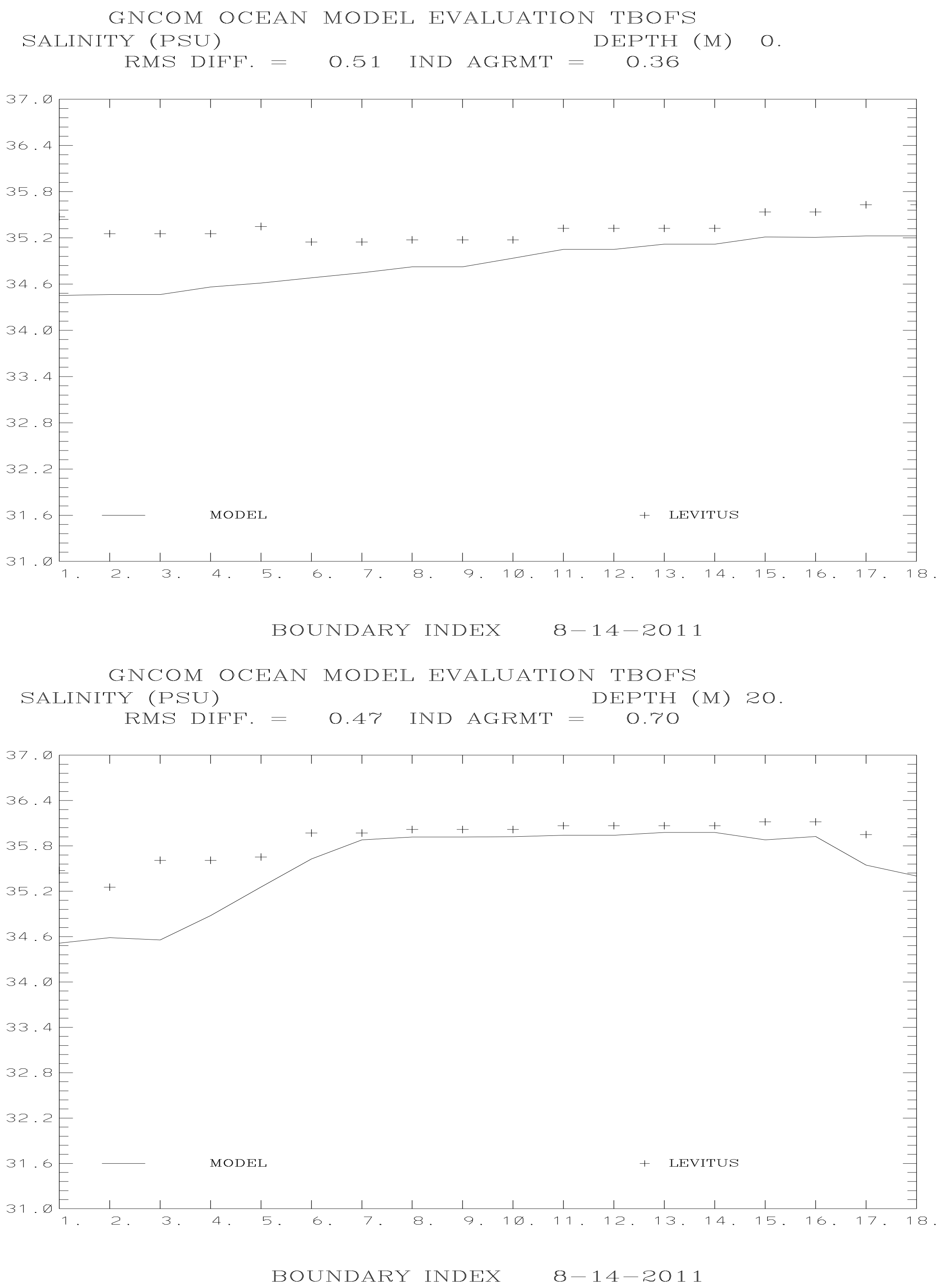
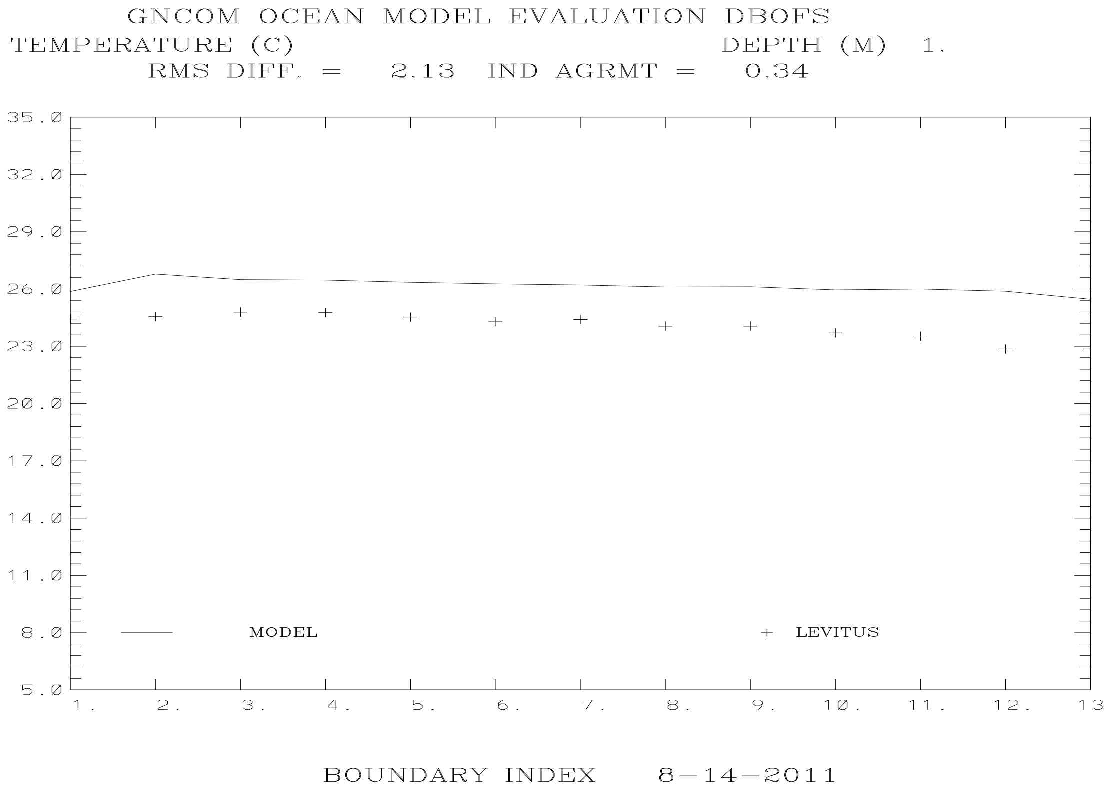


Figure 6.5. GNCOM surface and near bottom salinity at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.



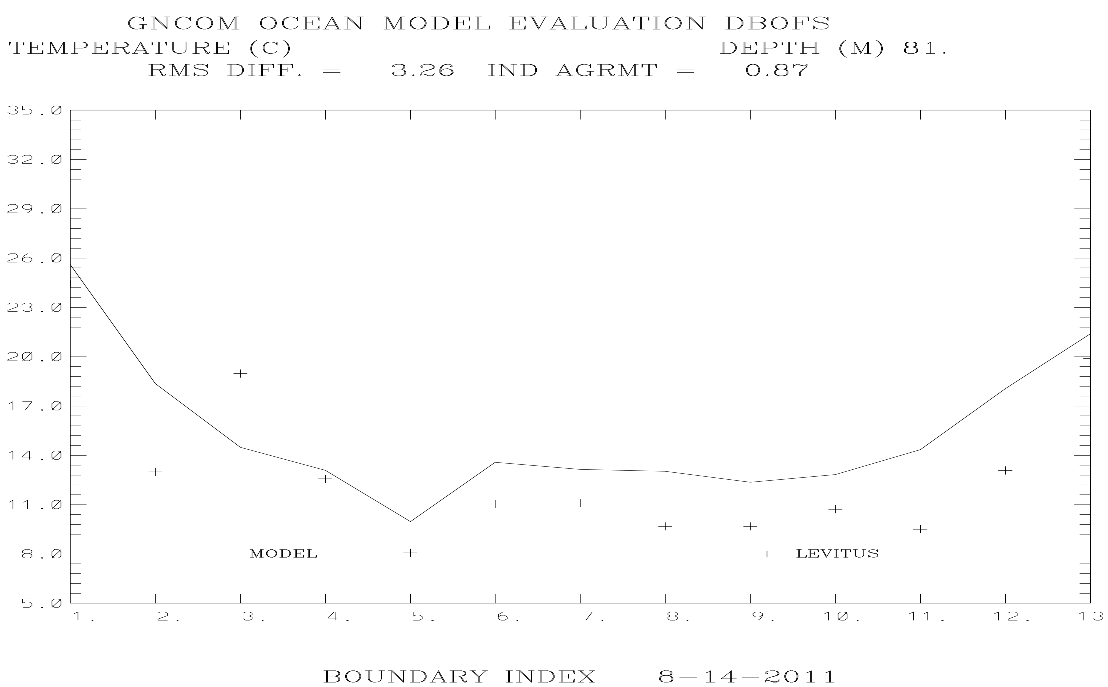
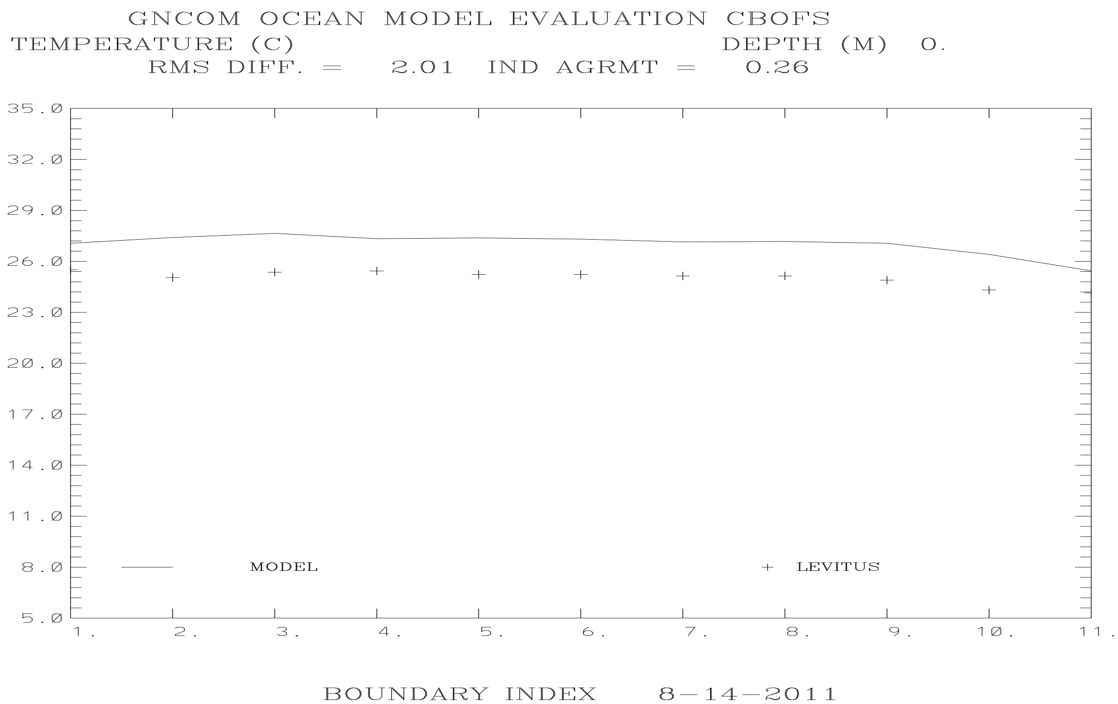


Figure 6.6. GNCOM surface and near bottom water temperature at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.



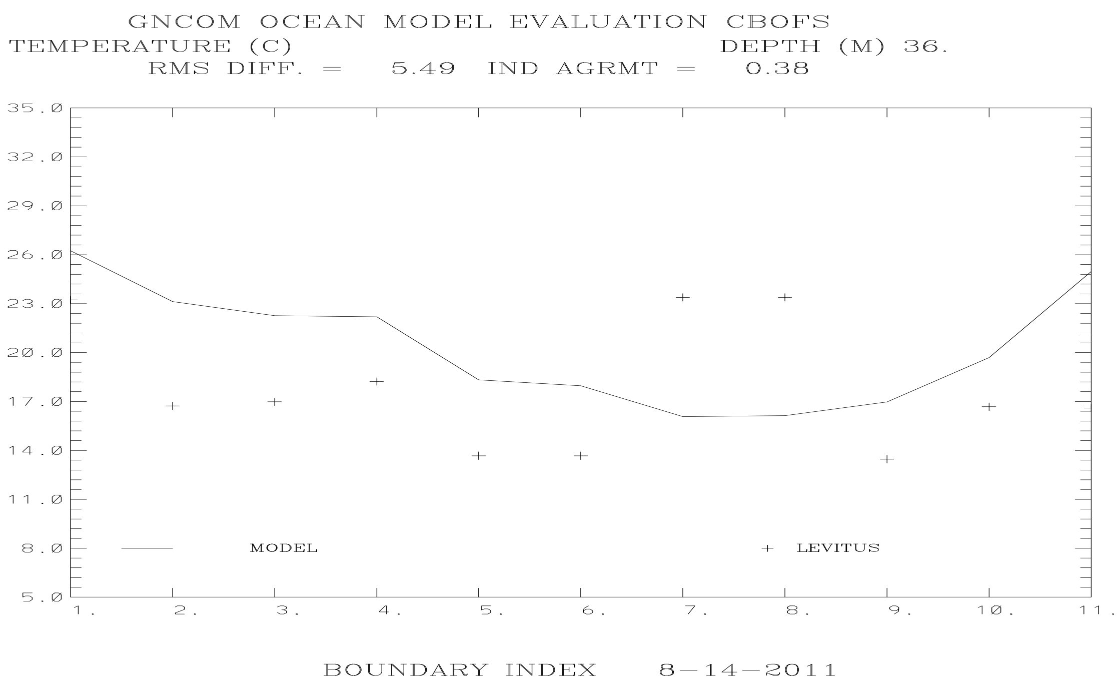
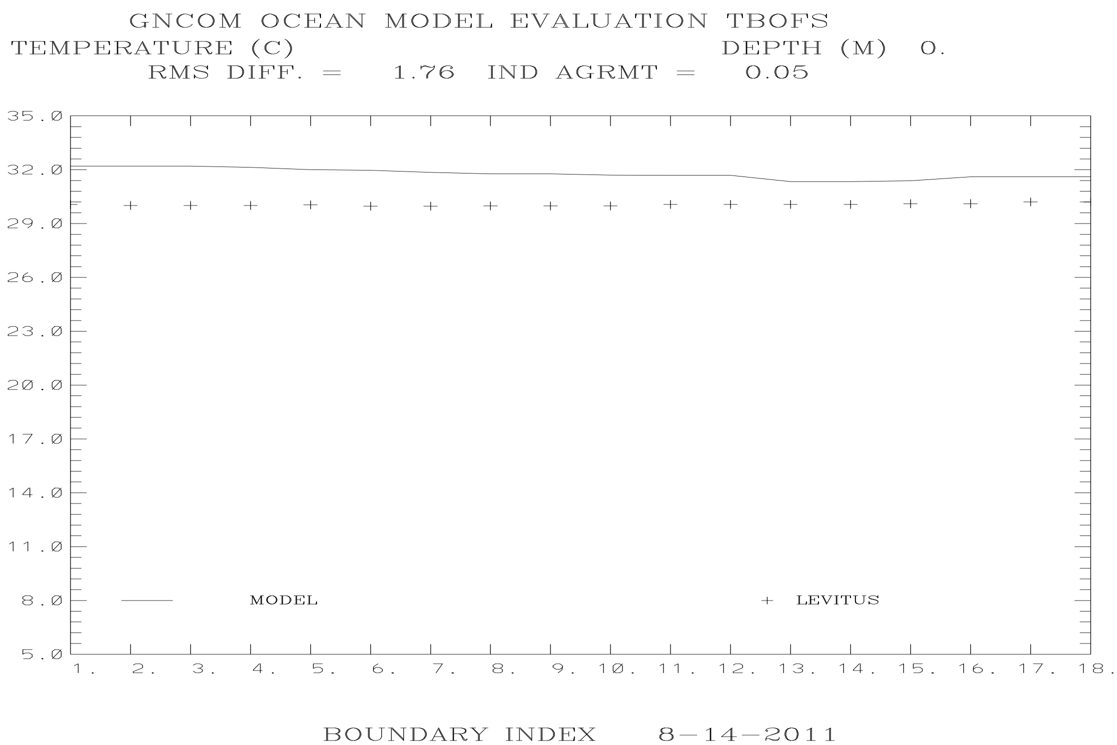


Figure 6.7. GNCOM surface and near bottom water temperature at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



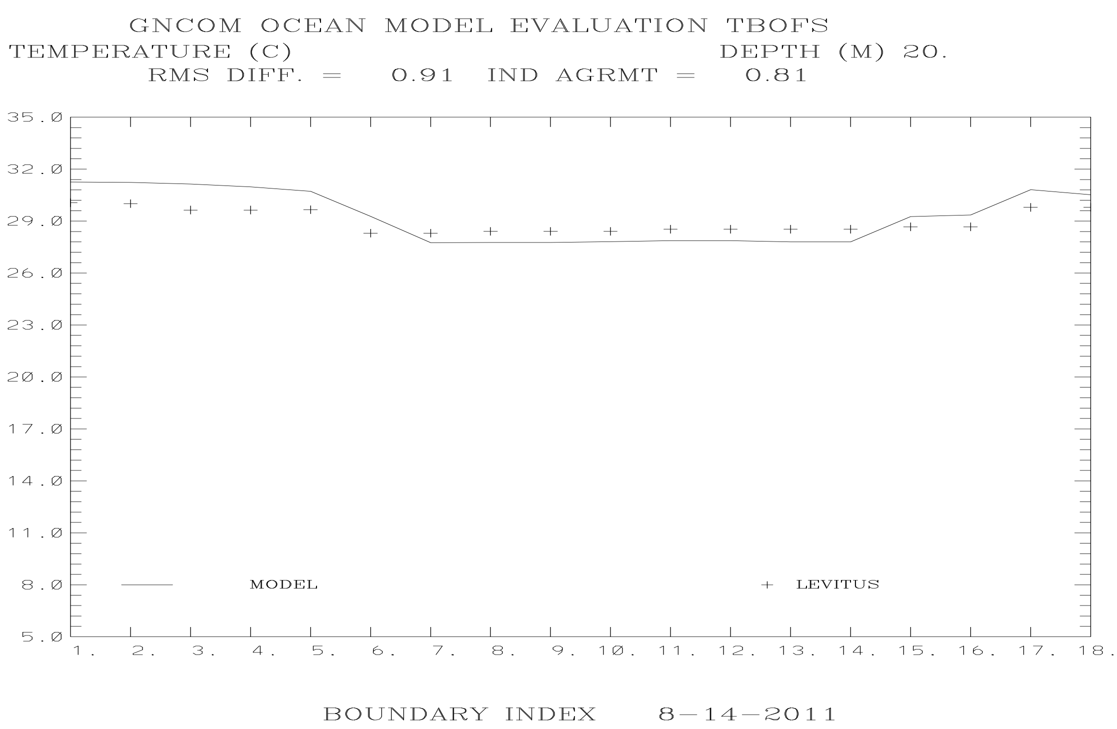


Figure 6.8. GNCOM surface and near bottom water temperature at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10^{th} grid point along the TBOFS open boundary.

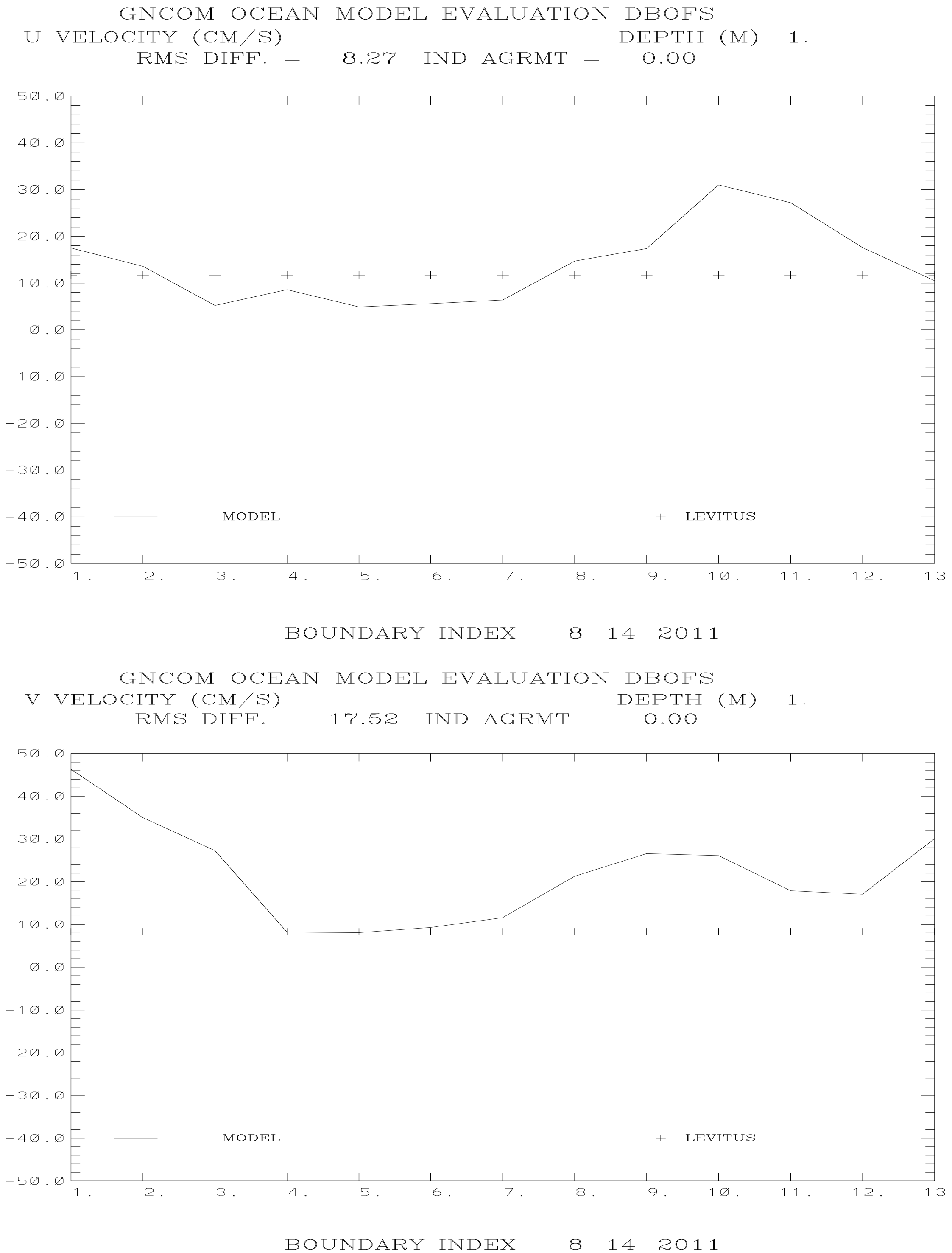


Figure 6.9. GNCOM surface U (East) and V (North) components at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the DBOFS open boundary.

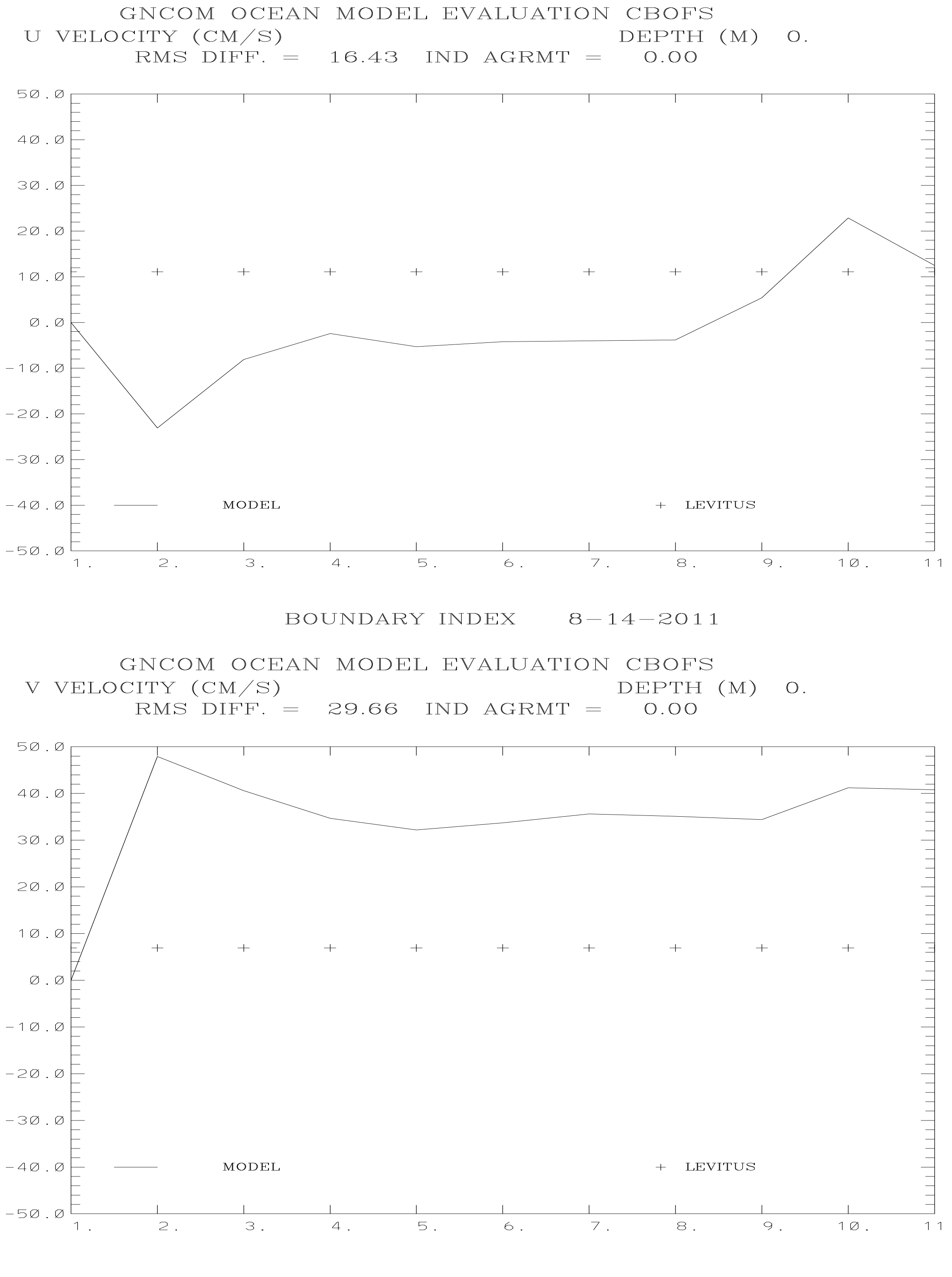
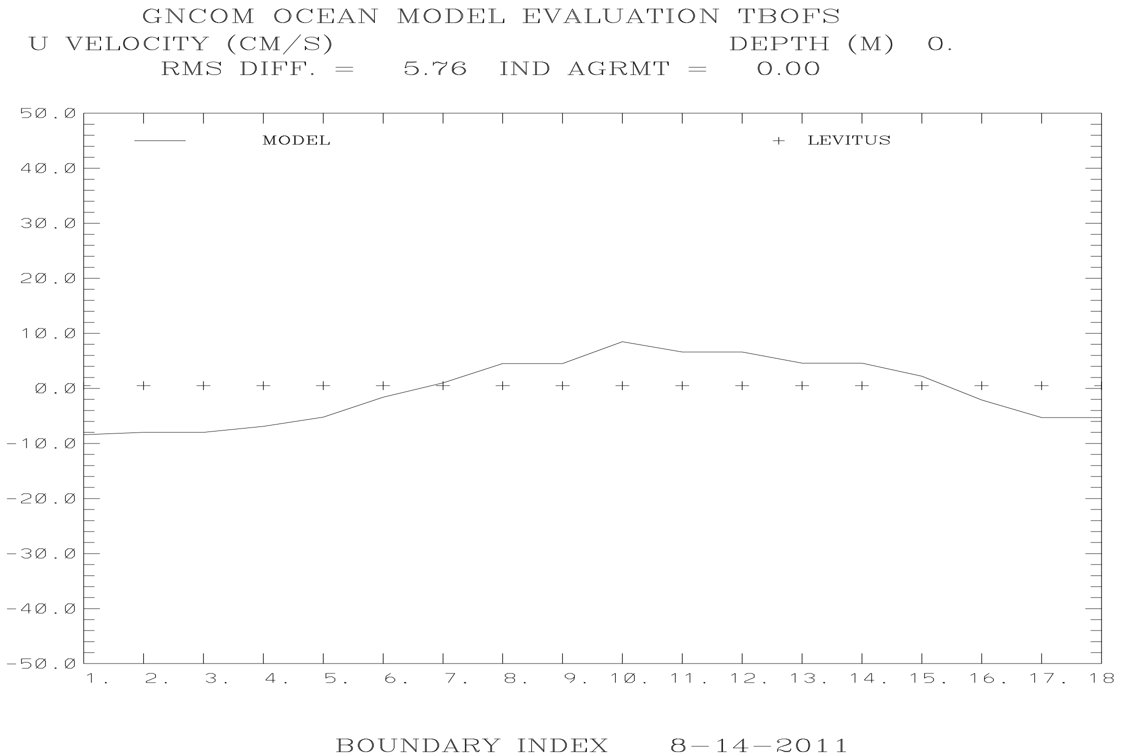


Figure 6.10. GNCOM surface U (East) and V (North) components at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the CBOFS open boundary.



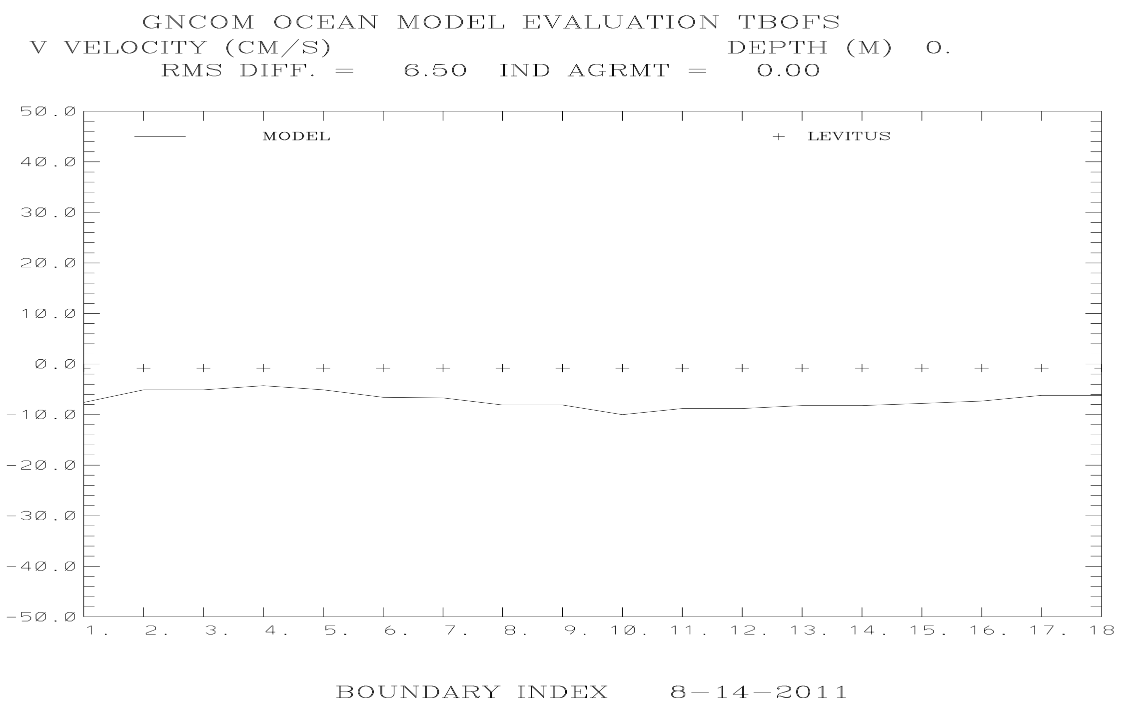


Figure 6.11. GNCOM surface U (East) and V (North) components at the start of the 8/14/2011 00 UTC forecast versus WOA 2001 climatology at every 10th grid point along the TBOFS open boundary.

7. SUMMARY AND CONCLUSIONS

A new analysis and plot program software package has been developed for the evaluation of ocean forecast model's (RTOFS and G-NCOM) salinity, water temperature, and water current forecast guidance and for the comparison of predictions along the open ocean boundaries of each of NOS' new ROMS based operational oceanographic forecast modeling systems. Salinity and water temperature are referenced to WOA 2001 climatology, while velocity predictions are referenced to the ADCIRC tidal inversion based vertically integrated tidal velocities and a WOA 2001 based geostrophic velocity. RTOFS forecast guidance was not available for May and August 2011. Based on the results for November 2010 and February 2011 the following analysis results are listed:

1. Velocity forecast guidance averaged along the three OFS open boundaries for G-NCOM and RTOFS agree in general direction and for the most part are within 26 cm/s. Since comparisons are made at a single point in time, some caution must be exercised in comparing the velocity forecast guidance.

2. Along the DBOFS open boundary, the G-NCOM surface salinity forecast guidance is nearer the WOA 2001 climatology than the RTOFS surface salinity forecast guidance. This is true as well for the stratification, which for G-NCOM is very close to climatology, while the RTOFS stratification is less pronounced. The mean surface salinity difference is order 2.5 PSU, with RTOFS being saltier than G-NCOM. For surface water temperature forecast guidance, RTOFS tends to be warmer by order 1^{o}C and less stratified than the G-NCOM values, which are very close to climatology.

3. Along the CBOFS open boundary, the G-NCOM surface salinity forecast guidance is nearer the WOA 2001 climatology than the RTOFS surface salinity forecast guidance. This is true as well for the stratification, which for G-NCOM is very close to climatology, while the RTOFS stratification is less pronounced. The mean surface salinity difference is order 2.3 PSU, with RTOFS being saltier than G-NCOM. For surface water temperature forecast guidance RTOFS tends to be warmer by order 0.5^{o}C and less stratified than the G-NCOM values, which are very close to climatology.

4. Along the TBOFS open boundary, the G-NCOM and RTOFS surface salinity forecast guidance are nearly equal and close to the WOA 2001 climatology. This is true as well for the stratification, with both G-NCOM and RTOFS very close to climatology. For surface water temperature forecast guidance G-NCOM and RTOFS agree to within 0.1^{o}C and are very close to climatology.

5. While limited TESAC format CTD data versus forecast model comparisons were performed, comparisons were less favorable up the estuaries (mid-Chesapeake Bay station) and near the northern forecast model boundaries.

8. RECOMMENDATIONS

The snapshot analysis procedures developed here are sufficient to perform a general evaluation of the salinity and water temperature forecast guidances as well as to note the difference in forecast guidance for water currents.

Recommendation #1. It would be useful to consider additions to the present snapshot analysis procedures as follows:

1. Perform the analyses at additional snapshot times at 12, 24, and 48 forecast hours. Additional TESAC format CTD comparisons should be considered. In fact, it may be useful to assign a particular TESAC format CTD station for each OFS open boundary for analysis.

2. Incorporate the recent updates to the WOA 2001 climatology to use as reference salinity, water temperature, and geostrophic velocity.

Recommendation #2. It would be useful to develop a complementary time series based evaluation procedure using the following approach:

1. Select 4 to 8 points covering the entire NOS OFS open ocean boundary and extract time series at these locations from the hourly to three-hourly water surface elevation, density, and water current ocean model forecast fields.

2. Compare ocean model time series forecast guidances for water levels, density, and water currents at each boundary point in terms of RMS difference and Willmott et al. (1985) relative error and NOS formal skill assessment statistics (NOS, 1999; Hess et al., 2003, and Zhang et al., 2009).

Recommendation #3. Additional evaluations of new operational ocean models such as the NCEP's HYCOM based Global-RTOFS should be performed. In the future, the ocean model evaluations should be extended to include the West Coast and Alaska.

Recommendation #4. The extension of the analysis procedures to include sea surface temperature and salinity, High Frequency Radar (HF radar), and shipboard Acoustic Doppler Current Profiler (ADCP) water current data should be further investigated.

Recommendation #5. Comparisons of the total and subtidal water level forecasts to observations should be performed on a routine basis (monthly to quarterly) using the automated water level software package (Schmalz and Richardson, 2011).

Recommendation #6. It is recommended that a more formal water level, density, and water current analysis protocol and schedule be developed in conjunction with NCEP and CO-OPS to systematically evaluate and compare ocean model forecasts along NOS OFS open boundaries. The forecast guidance source and output format should be stable and not subject to frequent change.

ACKNOWLEDGMENTS

Dr. Frank Aikman, Chief of Marine Modeling and Analysis Programs, Coast Survey Development Laboratory (CSDL) provided overall project direction and critical resources. Liyan Liu, National Weather Service's Environmental Modeling Center, provided guidance on how to read the TESAC CTD files. Jason Greenlaw, CSDL, provided the plots of the ROMS-based DBOFS, CBOFS, and TBOFS model grids. Scott Cross, National Coastal Data Development Center, provided updates on the status of the Ocean NOMADS server with respect to the availability of the RTOFS-Atlantic forecast files.

REFERENCES

Barron, C.N., A.B. Kara, H.E. Hurlburt, C. Rowley, and L.F. Smedstad, 2004: Sea surface height predictions from the Global Navy Coastal Ocean Model (NCOM) during 1998-2001. *Journal of Atmospheric and Oceanic Technology.*, 21(12), 1876-1894.

Barron, C.N., A.B. Kara, P.J. Martin, R.C. Rhodes, and L.F. Smedstad, 2006: Formulation, implementation and examination of vertical coordinate choices in the global Navy Coastal Ocean Model (NCOM). *Ocean Modeling*, 11, 347-375.

Bleck, R., G. Halliwell, A. Wallcraft, S. Carroll, K. Kelley, and K. Rushing, 2002: *HYCOM User's Manual*, Manual Version 2.0.01.

Blumberg, A.F. and G.L. Mellor, 1987: A Description of a Three-dimensional Ocean CirculationModel, in **Three Dimensional Coastal Ocean Models**, N.S. Heaps (editor), American Geophysical Union, Washington, DC.

Blumberg, A.F. and H.J. Herring, 1987: Circulation Modeling Using Orthogonal Curvilinear Coordinates, in **Three-Dimensional Models of Marine and Estuarine Dynamics** (J.C.J. Nihoul and B.M. Jamart, eds), Elsevier Oceanography Series, 45, 55-88.

Conkright, M.E., R. A. Locarnini, H.E. Garcia, T.D. O'Brien, T.P. Boyer, C. Stephens, J.I.Antonov, 2002: *World Ocean Atlas 2001: Objective Analyses, Data Statistics,and Figures, CD-ROM Documentation,* National Oceanographic Data Center, Silver Spring, MD, 17 pp.

Egbert, G.D. and S.Y. Erofeeva, 2002: Efficient Inverse Modeling of Barotropic Ocean Tides, *Journal of Atmospheric and Oceanic Technology*, 19(2), 183-204.

Hess, K.W., T.F. Gross, R.A. Schmalz, J.G.W. Kelley, F. Aikman, E. Wei, and M.S. Vincent, 2003: NOS Standards for Evaluating Operational Nowcast and Forecast Hydrodynamic Model Systems*, NOAA Technical Report NOS CS 17*, Silver Spring, MD.

Kolar, R.L, W.G. Gray, J.J. Westerink, and R.A. Luettich, 1994: Shallow Water Modeling in Spherical Coordinates: Equation Formulation, Numerical Implementation, and Application, *Journal of Hydraulic Research*, 32, 3-24.

Luettich, R.A., J.J. Westerink, and N.W. Scheffner, 1992: ADCIRC: An Advanced Three-dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL, *USACE Technical Report DRP-92-6*, Vicksburg, MS.

Martin, P.J., 2000: Description of the Navy Coastal Ocean Model Version 1.0, *NRL Report FR/7322-00-9962*, Stennis Space Center, MS.

Mehra, A. and I. Rivin, 2010: A Real Time Ocean Forecast System for the North Atlantic Ocean, *Terrestial, Atmospheric, and Ocean Sciences*, 21, 1, 211-228.

Mukai, A.Y., J.J. Westerink, and R.A. Luettich, 2001: Guidelines for Using the Eastcoast 2001 Database of Tidal Constituents within the Western North Atlantic Ocean, Gulf of Mexico and Caribbean Sea, US Army Corps of Engineers, *Coastal and Hydraulic Engineering Technical Note (IV-XX)*, Vicksburg, MS.

Myers, E. P. June 22, 2007: Personal Communication (edward.myers@noaa.gov)

NOS, 1999: NOS Procedures for Developing and Implementing Operational Nowcast and Forecast Systems for PORTS, *NOAA Technical Report NOS CO-OPS 0020*, Silver Spring, MD.

Richardson, P.H. and R.A. Schmalz, 2007: Comparison of NOAA Water Level Forecast Guidance from the Real Time Ocean Forecast System, Extratropical Storm Surge System, and the National Ocean Service Gulf of Mexico System: January-April 2006 Monthly Analysis. NOAA, National Ocean Service, Coast Survey Development Laboratory, **CSDL Informal Technical Note No. 8**, Silver Spring, MD.

Richardson, P.H. and R.A. Schmalz, 2009: Evaluation of National Weather Service and Extramural Water Level Forecast Guidance from Real Time Ocean Forecast Systems. NOAA, National Ocean Service, Coast Survey Development Laboratory, **CSDL Technical Memorandum 22**, Silver Spring, MD.

Rowley, C., C. Barron, L. Smedstad, and R. Rhodes, 2002: Real-time Ocean Data Assimilation and Prediction with Global NCOM, *Proceedings of MTS/IEEE Oceans 2002 Conference*, Biloxi, MS, 781-786.

Schmalz, R.A. and P.H. Richardson, 2011: Automated Evaluation of Water Level Forecast Guidance from NWS and Extramural Real Time Ocean Forecast Systems, **NOAA Technical Memorandum, NOS CS 25**, Silver Spring, MD, 69p.

UNESCO-IOC, 2010: GTSPP Real-Time Quality Control Manual, First Revised Edition, IOC Manuals and Guides No. 22.

Willmott, C. J., S. G. Ackleson, R. E. Davis, J. J. Feddema, K. M. Klink, D.R. Legates, J. O'Donnell, and C. M. Rowe, 1985: Statistics for the Evaluation and Comparison of Models, *Journal of Geophysical Research*, 90, 8995-9005.

Zhang, A., K.W. Hess, E. Wei, and E. Myers, 2009: Implementation of Model Skill Assessment Software for Water Level and Water current in Tidal Regions, **NOAA Technical Report NOS CS 24**, Silver Spring, MD.

APPENDIX A. Downloading Operational Model Files from the Ocean NOMADS Site

RTOFS Ocean Model:

1. Enter Ocean NOMADS website at http//edac-dap2.northerngulfinstitute.org/ocean_nomads/.

2. Click on "NOAA Real Time Ocean Forecast System – Atlantic (RTOFS-Atlantic)" link.

3. Click on "OPeNDAP (THREDDS)" link.

4. Click on ofs.yearmody/, where year is the year (2010), mo is the month, and dy is the day. For example, ofs.20101115/.

5. There will be a series of seven files listed. Click on the file ofs_atl.t00 UTC.N000.grb.nc.

6. Click on the file which follows OPeNDAP:

7. Scroll down and click box next to WTMPC: Grid. For depth, fill in with values 0:1:11. For y, fill in values 963:1:1297. For x, fill in values 606:1:980.

8. Scroll down and check box next to SALIN: Grid. Fill in the same values for depth, y, and x as were done for step seven.

9. Scroll back to top of page and hit the "Get ASCII" button.

10. After data appears on screen, click on "FILE" and "Save as".

11. Name file such as "rtofs.st.yearmody" and save.

12. Return to OPeNDAP Dataset Access Form.

13. Scroll down to VOGRD and check the box. For depth, fill in with values 0:1:11. For the U and V components it is necessary to decrement and increment the indices for y and x. For y, fill in values of 962:1:1298. For x, fill in values of 605:1:981.

14. Scroll down to UOGRD and check the box. Fill in the same index values for depth, y, and x as were done for step 13.

15. Hit the "Get ASCII" button and download the file as before. Name file as rtofs.uv.modyyear. File will be saved as rtofs.uv.modyyear.mht.

NCOM Ocean Model:

1. Return to Ocean NOMADS homepage.

2. Click on the "Navy Global Coastal Ocean Model (Global NCOM)" link.

3. Click on the "THREDDS" link of NCOM Region 1 with the Domain of the Gulf of Mexico, Caribbean, and Western North Atlantic.

4. Click on the link to the desired model data file. This will bring up the OPeNDAP Dataset Access Form.

5. Scroll down to water_temp: Grid and click the box. For depth, enter 0:1:23. For lat, enter 216:1:320. For lon, enter 120:1:216.

6. Scroll down to salinity: Grid and enter the same values for depth, lat, and lon.

7. For NCOM model files, water temperature, salinity, U component of velocity, and V component of velocity can be downloaded in one step.

8. Scroll down to water_u: Grid and click the box. For depth, enter 0:1:23. For latitude, enter 215:1:321. For longitude, enter 119:1:217.

9. Go to the top of the page and hit the "Get ASCII" button. Save the file such as ncom.yearmody. The file will be saved as ncom.yearmody.mht.

10. Exit the Ocean NOMADS site.

APPENDIX B. Directory Structures

1. Create and populate the following directory structures:

Prod: directory	data.yearmody: directory
eval.ofs.n	rtofs.st.yearmody.mht
evaldp.sh	rtofs.uv.yearmody.mht
source	ncom.yearmody.mht
plot	ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmoddy.dat
grid	

Source is a subdirectory which contains the analysis source file.
The subdirectory plot contains the script, evaldp_plot.sh, for running the plot program.
Grid is a subdirectory containing the necessary grid files ncom.grid, nos.ofs.cbofs.romsgrid.nc, nos.ofs.dbofs.romsgrid.ver1.1.nc, nos.ofs.tbofs.romsgrid.nc.

2. Move operational model files previously downloaded from PC to desired work directory: data.yearmody.

3. Copy the model files renaming them as rtofs.ts.yearmody, rtofs.uv.yearmody, and ncom.yearmody.

4. To obtain daily ctd.profile files go to NCEP CCS RTOFS daily forecast directory: /gpfs/c/nco/ops/com/ofs/prod and copy the file: ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmody.txt

   to your DESKTOP using WINSCP. Then transfer this file to the directory in 1. above. To obtain ownership execute the following commands:

   cat ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmody.txt ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmody.dat
   rm ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmody.txt

APPENDIX C. Editing the Operational Model Files

Rtofs.ts.modyyear:

l. Delete top portion of file down to the line that begins with WTEMPC.WTEMPC. There will be three numbers in brackets that follow.

2. On the line which begins with WTEMPC.WTEMPC, move to the left hand bracket of the first number, then hit i for insert and <return>. This will create a second line with the three numbers in brackets.

3. To remove the left hand brackets, type the following command :1,$s/\[/ /g. All the left hand brackets will be replaced with an empty space. Use the same command to remove the right hand brackets.

4. To remove the "=" sign, use the command :1,$s/=//g. To remove the commas, type :1,$s/,//g.

5. Search for "WTMPC.WTMPC". Delete the line that begins with WTMPC.depth and the line which follows. Delete the line that begins with WTMPC.y and the lines that follow. Delete the line that begins with WTMPC.x and the lines that follow.

6. This will bring you to a line that starts with "SALIN.SALIN". Use insert to move the three numbers that follow to a second line.

7. Go to the end of the file. Delete the lines that start with SALIN.depth, SALIN.y, and SALIN.x, and all lines which follow.

Rtofs.uv.modyyear:

1. Edit the file rtofs.uv.yearmody. Delete top portion of file down to the line that begins with VOGRD.VOGRD. Use insert to move the three numbers that follow to a second line.

2. To remove the left hand brackets, type the following command :1,$s/\[/ /g. All the left hand brackets will be replaced with an empty space. Use the same command to remove the right hand brackets

3. To remove the "=" sign, use the command :1,$s/=//g. To remove the commas, type :1,$s/,//g.

4. Search for "VOGRD.VOGRD". Delete the line that begins with VOGRD.depth and the line which follows. Delete the line that begins with VOGRD.y and the lines that follow. Delete the line that begins with VOGRD.x and the lines that follow.

5. This will bring you to a line that starts with UOGRD.UOGRD. Use insert to move the three numbers which follow to a second line.

6. Go to the end of the file. Delete the lines that start with UOGRD.depth, UOGRD.y, and UOGRD.x, and all lines which follow.

Ncom.modyyear:

1. Delete top portion of file down to the line that begins with water_temp.water_temp. Use insert to move the four numbers that follow to a second line.

2. Use command :1,$s/\[/ /g to remove the left hand brackets. Use command :1,$s/\]/ /g to remove the right hand brackets.

3. Use command :1,$s/=//g to remove the “=” signs. Use command :1,$s/,//g to remove the commas.

4. Search for “water”. Delete the line which begins with water_temp.time and the line which follows. Delete the line that begins with water_temp.depth and the two lines which follow. Delete the line that begins with water_temp.lat and the lines which follow. Delete the line that starts with water_temp.lon and the lines which follow.

5. This brings you to a line that starts with “salinity.salinity”. Use insert to move the four numbers that follow to a second line. Search again for “water”.

6. This brings you to a line that starts with “water_u.water_u”. Scroll up, then delete the line that begins with salinity.time, salinity.depth, salinity.lat, and salinity.lon, and all the lines which follow.

7. This brings you back to the line which begins with “water_u.water_u”. Use insert to move the four numbers which follow to a second line.

8. Search for the next occurrence of “water”. Delete the lines which begin with water_u.time, water_u.depth, water_u.lat, water_u.lon, then delete the lines which follow.

9. This brings you to the line which begins with “water_v.water_v”. Use insert to move the four numbers which follow to a second line.

10. Search for next occurrence of “water”. Delete lines which begin with water_v.time, water_v.depth, water_v.lat, and water_v.lon, and all the lines which follow.

APPENDIX D. **Running the Analysis and Plot Programs**

1. Cd into the prod directory.

2. To run the analysis program, type in the following command:
   evaldp.sh mm dy year.
   Ex. evaldp.sh 11 10 2010

3. The program creates the following output files in prod:
   checkp.adcirc
   checkp.ctd.11102010
   checkp.grid
   checkp.levitus
   ctd.ncom.11102010
   ctd.rtofs.11102010
   evalp.ctd.11102010
   evalp.sum.ts.11102010
   evalp.sum.uv.11102010
   printout.evald.11102010
   ts.ncom.11102010
   ts.rtofs.11102010
   uv.ncom.11102010
   uv.rtofs.11102010

4. Cd into the directory plot. To run the plot program, type
   evaldp_plot.sh model mo dy year.
   Ex. evaldp_plot.sh rtofs 11 10 2010

   The plot program will generate the following output:
   gmeta.rtofs.11102010
   ps.rtofs.11102010
   rtofs.plot.out.11102010
   sum.s.ctd.rtofs.11102010
   sum.s.mean.ts.rtofs.11102010
   sum.s.rms.ts.rtofs.11102010
   sum.t.ctd.rtofs.11102010
   sum.t.mean.ts.rtofs.11102010
   sum.t.rms.ts.rtofs.11102010
   sum.u.mean.adcirc.rtofs.11102010
   sum.u.mean.levitus.rtofs.11102010
   sum.u.rms.adcirc.rtofs.11102010
   sum.u.rms.levitus.rtofs.11102010
   sum.v.mean.adcirc.rtofs.11102010
   sum.v.mean.levitus.rtofs.11102010

sum.v.rms.adcirc.rtofs.11102010
sum.v.rms.levitus.rtofs.11102010
ps.rtofs.11102010 is the postscript plot file.

5. Similarly for NCOM, run the plot program as follows:
   evaldp_plot.sh ncom 11 10 2010

   The plot program will generate the following output:
   gmeta.ncom.11102010
   ps.ncom.11102010
   ncom.plot.out.11102010
   sum.s.ctd.ncom.11102010
   sum.s.mean.ts.ncom.11102010
   sum.s.rms.ts.ncom.11102010
   sum.t.ctd.ncom.11102010
   sum.t.mean.ts.ncom.11102010
   sum.t.rms.ts.ncom.11102010
   sum.u.mean.adcirc.ncom.11102010
   sum.u.mean.levitus.ncom.11102010
   sum.u.rms.adcirc.ncom.11102010
   sum.u.rms.levitus.ncom.11102010
   sum.v.mean.adcirc.ncom.11102010
   sum.v.mean.levitus.ncom.11102010
   sum.v.rms.adcirc.ncom.11102010
   sum.v.rms.levitus.ncom.11102010

APPENDIX E. Processing Notes: February 2011

1. When renaming RTOFS ts file it should be named "rtofs.st.yearmody".

2. When editing RTOFS and G-NCOM files, make sure to remove all blank lines.

3. Be careful with year/month/day convention.

   rtofs.st.modyyear
   rtofs.uv.modyyear
   ncom.modyyear
   ofs_atl.t00 UTC.ctd.profiles.TESAC.yearmody.dat

4. NOMADS point of contact is Scott L. Cross, scott.cross@noaa.gov, 843-762-8567.

5. Ocean NOMADS servers will be transferred from the Northern Gulf Institute to NCDDC servers in Charleston, SC. In addition, aggregate products will become available to access time series at user selected grid points.

6. We have not been able to access OpeNDAP (THREDDS) for RTOFS Atlantic 3D forecasts for several days. Apache/2.2.3 (Red Hat) Server at edac-dap2.northerngulfinstitue.org Port 80 is not available. However, the grib and netCDF files are available on this same server.

APPENDIX F. Analysis Notes: February 2011

1. The velocities along the NOS OFS boundaries for the G-NCOM were always positive or zero.

2. In reviewing, Subroutine read_ncom, all negative velocities were limited to zero. This was by an error caused by extending the salinity and water temperature checking procedures to velocity.

3. Subroutine read_ncom was revised to use the -30000 value as the missing data value for all hydrodynamic fields. Refer to the diff file listed below.

Diff File:

```
407a408
>
421d421
< c     nbtt=nbt/nincr +1
826a827
>       data dmiss/-30.0D3/,tol/0.1D0/
843,844c844
<       t(j,i,k)=sf*t(j,i,k) + off
<       if(t(j,i,k) .lt. 0.)then
---
>       if(t(j,i,k) .lt. dmiss + tol)then
846a847
>       t(j,i,k)=sf*t(j,i,k) + off
865,866c866
<       s(j,i,k)=sf*s(j,i,k) + off
<       if(s(j,i,k) .lt. 0.)then
---
>       if(s(j,i,k) .lt. dmiss + tol)then
868a869
>       s(j,i,k)=sf*s(j,i,k) + off
887,888c888
<       u(j,i,k)=sf*u(j,i,k)
<       if(u(j,i,k) .lt. 0.)then
---
>       if(u(j,i,k) .lt. dmiss + tol)then
890a891
>       u(j,i,k)=sf*u(j,i,k)
909,910c910
<       v(j,i,k)=sf*v(j,i,k)
<       if(v(j,i,k) .lt. 0.)then
---
>       if(v(j,i,k) .lt. dmiss + tol)then
912a913
>       v(j,i,k)=sf*v(j,i,k)
```